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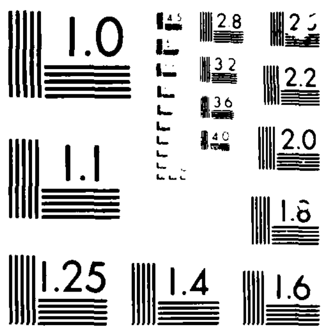
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EVALUATION OF A VISUAL SYSTEM IN ITS SUPPORT OF SIMULATED HELICOPTER FLIGHT

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February 1986

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Visual System Component Development Program (VSCDP) was developed by GE under contract with PM TRADE and installed at Williams AFB in spring 1985. Its purpose was to expand the state-of-the-art in visual systems by providing the capability to support nap-of-the-earth (NOE) flight simulation, which requires a high density of visual cues to allow pilots to accurately judge veritcal and horizontal distances.

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The GE system was tested with the computer generated imagery projected in the dome with a radius of 12 feet. The Field of View (FOV) was 140 degrees horizontal by 60 degrees vertical with an enhanced Area of Interest (AOI) of 26 degrees horizontal by 20 degrees vertical inserted in the middle. The imagery centered in pilot's attention regardless of where he was looking in the dome; however, the eye tracker was not functioning for these tests.

Nine experienced helicopter pilots participated as subjects. Two kinds of flight mission plans were used: a familiarization flight and a tactical maneuvers flight. The results of the experiment showed that the GE system can support all aspects of helicopter flight simulation. However, problems were found that indicate further work is needed. These included trouble with perceived sizes and distances in the visual scene, and a high incidence of simulator sickness, probably due to processing of motion cues.

FOREWORD

This report documents an evaluation of a simulator visual system developed by General Electric Company as part of PM TRADE's Visual System Component Development Program (VSCDP). Data for the evaluation were collected at the Air Force Human Resources Laboratory (AFHRL), Williams Air Force Base, Arizona. The evaluation was completed by Seville Training Systems under subcontract with Science Applications International Corporation.

A number of persons assisted during the evaluation. Foremost were the Army helicopter pilots who flew the system and provided most of the data. These pilots were:

MAJ James R. Correia
CW4 Carl R. Heinze
CW4 Ray Hixon
CW4 Jack A. Lease
LTC John T. Litchfield
CAPT Gerald L. Paratore
CW4 Kenneth P. Shriver
CW4 James R. Taylor

Major Correia was an Army experimental test pilot stationed at Fort Rucker, AL. The other seven pilots were Army test pilots connected with AH-64 acceptance testing at McDonnell Douglas Helicopter Company, Mesa, Arizona. One of the Seville investigators, Winon E. Corley, a retired Marine and Coast Guard pilot, also served as a pilot during the evaluation.

Thanks are also due LTC Carl R. Propp and LTC Jimmy B. Smith who are with the AH-64 acceptance testing program and who arranged for the Army pilots at McDonnell Douglas to be available. Dr. Melvin L. Thomas of AFHRL at Williams was especially helpful through managing numerous administrative details before and during the tests, and J. Peter Gerlicher of AFHRL consulted with the investigators and helped in handling numerous details. Gene B. Wiehagen, who was the Contracting Officer's Technical Representative, and Arthur G. Cannon, both of PM TRADE, assisted through scheduling availability of the visual system and establishing contacts with Army personnel who provided the pilots for the flight tests. Several GE personnel on site at Williams went to great lengths in operating the system and in fulfilling requests for special conditions and observations: Dr. William S. Beamon, Jeffery A. Clark, Bryce J. Ericksen, Fernando B. Neves, and Dr. Edward M. Sims.

Benjamin B. Blood, Jr., SAIC Principal Investigator for the project under which this study was funded, kept all arrangements with AFHRL, PM TRADE, and Seville running smoothly in spite of scheduling problems. Dr. William D. Spears directed the project for Seville, and Dr. Wallace W. Prophet served as Seville's Program Manager.

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I. INTRODUCTION AND APPROACH

During late September and early October 1985, Seville Training Systems collected data for an evaluation of a computer-based visual system which is designed to support training of Army helicopter operations in flight simulators. This report presents the results of the evaluation. It also addresses certain perceptual problems that appear to be increasing as simulations of visual scenes improve. In many cases the problems seem to stem from differences between mathematical descriptions of visual scenes, which characterize visual systems, and the nature of perceptual "reality" which typically has a far from one-to-one correspondence to mathematical descriptions of cues. It is believed that this discussion directs attention to substantive issues that need clarification.

There are three sections of the report, plus five appendices. The present section presents the background for the study, a statement of purpose, and the approach. Section II presents the results of the study and considerable discussion of them. Section III expands the discussion and includes the analysis of perceptual problems just mentioned. Appendices give detailed information regarding certain aspects of the approach and results.

BACKGROUND

Several years ago the U.S. Army Project Manager for Training Devices (PM TRADE) was tasked to develop specifications for a flight simulator to support training programs for the Army AH-64 attack helicopter. The training programs in which the simulator is to be used include initial crew qualification training, proficiency (recurrent) training of qualified AH-64 pilots, and AH-64 instructor pilot training. Thus, the device is to serve both institutional and unit training needs. In developing the specifications for the simulator, a number of concept formulation studies were completed in 1977.[1] Following these studies a draft specification was prepared and circulated for industry and Army review and comment. Based on the resulting comments, a revised set of specifications was prepared[2] that described a

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[1]CAE Electronics LTD. AH-64 flight and weapons simulator concept formulation study (Vols. 1 & 2). Saint-Laurent, Montreal, Quebec (Canada): Author, October 1977.

The Singer Company, Link Division. AAH study report (Tech. Rep. NAVTRAEQUIPCEN 77-C-0046-0001). Binghamton, NY: Author, July 1977.

Sperry SECOR. AH-64 flight and weapons simulator concept formulations study (Vols. 1-3). Fairfax, VA: Author, September 1977.

American Airlines, Inc. U.S. Army advanced attack helicopter simulator concept. Fort Worth, TX: Author, November 1977.

[2]Naval Training Equipment Center. Specification for AH-64 combat mission simulator device 2B40. Orlando, FL: Author, April 1980.

design for an AH-64 combat mission simulator (CMS) presumably capable of providing pilot and copilot-gunner training in all tasks that the crew would have to perform during combat missions in the actual aircraft.

Nevertheless, questions subsequently arose as to whether the CMS described in the specifications would in fact meet the training requirements envisioned for it. To clarify the issues involved, Seville completed an analysis of simulator perceptual and behavioral support requirements as derived from AH-64 combat mission tasks.[1] It was concluded from this study that then current state-of-the-art CGI (computer generated imagery) could not provide adequate visual cueing for certain AH-64 mission tasks. Nap-of-the-earth (NOE) flight and related masking maneuvers were a special concern because they require that a pilot judge vertical and horizontal distances with a high degree of accuracy if he is to avoid contact with the terrain and vegetation while using them to maximum advantage during concealment. Rich surface textures and local surface irregularities are needed for such purposes, and CGI systems at that time could not provide them in sufficient quantities and patterns.

A visual system based on modelboard technology would overcome these difficulties to a considerable extent, but in doing so, other problems would surface, especially as related to versatility of targets and their locations and movements. (There are, of course, other disadvantages with modelboard visual systems, such as limitations on gaming areas and probe clearances for near objects and terrain.) Accordingly, PM TRADE sought to advance the state of the art in CGI through a solicitation[2] for the Visual System Component Development Program (VSCDP). The program was to accelerate the development of technology for the next generation of NOE combat mission visual simulators. In addition to NOE flight, a system developed under this program is to provide adequate visual support for battle scenarios including target acquisition, target engagement, and weapons effects. Two contracts were awarded as a result of the solicitation, one to General Electric Company, Electronic Systems Division, Daytona Beach, Florida, and one to Honeywell Training and Control Systems Operations, West Covina, California.

The GE system, which is the subject of this report, had been installed in facilities of the Air Force Human Resources Laboratory at Williams Air Force Base, Arizona. The system had undergone various engineering tests and had been demonstrated to numerous persons interested in and concerned about the development of CGI technology. The evaluation reported here began in late summer of 1985, and the data were collected between 24 September and 11 October, 1985.

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[1] Caro, P. W., Spears, W. D., Isley, R. N., & Miller, E. J. Analysis of the design of an AH-64 combat mission simulator (Technical Report TR 80-17). Pensacola, FL: Seville Research Corporation, December 1980.

[2] Solicitation No. N61339-82-R-0139. Visual system component development program (VSCDP). Orlando, FL: Naval Training Equipment Center, 8 October 1982.

STATEMENT OF PURPOSE

The purpose of the present study was to assess the extent to which the GE VSCDP system provides adequate visual support for Army helicopter operations. The assumption is that if the system is adequate for performing helicopter operations, it will also be adequate for training the skills required by those operations. Because of difficulties of past CGI systems with respect to certain critical maneuvers such as NOE, special emphasis was placed on NOE and related tasks. However, visual support for all basic segments and phases of attack helicopter missions was also a concern. If the visual system is adequate for overall mission practice, overall mission training can be enhanced as well. In addition, the visual system could then make a considerable contribution to the development of training systems for scout-attack helicopter teams, a current concern in the Army's development of an aviation combined-arms team trainer (ACATT).

APPROACH

There were two thrusts to the data collection. The principal thrust was to obtain evaluative data from pilots who flew the system, and who had considerable experience in attack helicopters. A variety of data were collected from pilots. In addition, data were collected by a training psychologist who had experience in the application of the psychology of perception to simulator visual systems. These latter data concentrated on the provision of visual information by VSCDP scenes, and the adequacy of perceptual determiners of the information. The discussions immediately following describe the GE system and the approach for the study as a whole and identify the types of data that were collected.

The GE Visual System

The visual system developed for VSCDP by GE was a product of GE's Advanced Visual Technology System (AVTS). The system is designed to drive any current display, but during the tests the scenes were projected on the interior surface of a dome having a 12-foot radius. The instantaneous background field of view (FOV) was 140° horizontal by 60° vertical. The scene could be enhanced in an area of interest (AOI) that was 26° horizontal and 20° vertical. The AOI was controlled by a head-tracker. The system design also includes an eye-tracker for the AOI, but the eye-tracker was not functioning at the time of the tests.

According to a preliminary engineering test of the system, background scenes had approximately 7.5 arc minutes of resolution, and the AOI 1.5 arc minutes. However, effective resolution at normal observer distances was probably somewhat less. Also, the illumination level had not yet reached the design goal of 4 footlamberts, and functional resolution by a perceiver would be reduced due to the low illumination level. (The preliminary engineering test found an average luminance of 0.9 footlamberts, but improvements were reported to have been made since the engineering test. Also, the illumination level increased during the present study with the replacement of a light valve.) The AOI was noticeably brighter than the background, but how much brighter was not known. The update rate for the scene was 60 hz, and there

was no noticeable transport delay in either the background or in shifts of the AOI.

From a phenomenal (in the sense of perception) standpoint, realism in scenes was quite striking. There was full color, and all normally three-dimensional features were represented as three-dimensional, with three-dimensional contours where appropriate. Trees especially appeared realistic, except when very close to them at which point they became blurred. There were some complaints by pilots about banks of (dry) streams being too straight, the absence of rocks in stream beds, too little ground cover, etc. Although these problems affected some pilots' evaluations of scenes as explained later, considerable scene realism was obtained overall. Another problem was an occasional jitter and flicker in scenes. This problem is correctable, and there was no evidence that it had a noticeable effect on pilots' evaluations.

The test arrangements did not include a simulation of a helicopter cockpit. Pilots sat on a high stool with a backrest, but without belt constraints. There was no instrumentation, so pilots had to depend on feedback from the visual scene for all immediate knowledge of aircraft status and movements. They wore a standard helmet which was wired to control the AOI. (Some pilots experienced discomfort with the helmet because of becoming too hot.) Self-motion through the scene could be controlled in two ways. There was a set of usual helicopter controls (collective, cyclic, and pedals), but after a preliminary trial with them it was felt that their use would be disconcerting to pilots. The controls had no realistic loading, and they were fatiguing to operate because centering could not be adjusted as desired. Hence, the second set of controls was used. These consisted of a joystick that could be inclined in any direction for horizontal movement; a twist-knob at the top of the joystick to provide yaw; and a separate sliding control to effect vertical movement. The joystick and sliding control were mounted on a small metal box which could be held in the lap while flying. Perhaps an additional advantage in using this control system instead of the helicopter controls was that it helped pilots remain aware that they were not flying and evaluating a helicopter simulator; they were to focus on the scene. The controls were simply a means to permit movement relative to the scene. Nevertheless, there were occasions when pilots appeared to be frustrated by the general lack of cockpit realism.

The area represented in the scene, a portion of the Hunter-Liggett Military Reservation in California, was approximately 3 by 7 nautical miles, although only a gaming area of 1 by 5 nautical miles actually had significant amounts of contours, vegetation, and object representation in the simulation. Tanks and trucks were simulated as targets, and they could have motion with dust trails. Own-ship motion was not restricted except that one could not go below ground level at the bottoms of valleys in the gaming area. Hence, if one "struck" a tree, tank, or hillside, he would simply go through it. There was a red flash on the screen, however, to indicate such contact. Visibility under daylight conditions could be varied up to the limits of the area represented, although except for two trial flights with 24,000 feet visibility, all flights were made with 60,000 feet visibility. Dawn or dusk and night conditions could be imposed. (The pilots could tell no difference between dawn and dusk conditions, so data obtained under either condition were combined under dawn-dusk, or DD.) A forward-looking infrared (FLIR) display was also

simulated. Although not planned originally, an effort was made to include FLIR-related data because of the importance of FLIR in attack training.

The visual scene experienced by a pilot could be monitored in full color on remote CRT displays. There were three such displays, two showing the background scene and one the AOI. In addition, a separate display presented a variety of information regarding aircraft status during flight. The information of most concern during the tests was altitude, ground speed, and $\underline{x}$, $\underline{y}$ coordinates for aircraft position. The coordinates were used in determining actual distances to objects when range estimations were made. A pilot would make an estimate from a known position, and then fly to the object for a second position reading.

Pilots

Nine helicopter pilots, all males, assisted in the evaluation. Eight of this group were currently in the Army. Of the Army pilots, five were AH-64 acceptance test pilots assigned to McDonnell Douglas Helicopter Company, and two were assigned to the Office of the Program Manager for Advanced Attack Helicopters at McDonnell Douglas. The eighth Army pilot was in the Apache Test Branch at Ft. Rucker, Alabama. Ages for the Army group ranged from 33 to 39, with a mean of 37.4. The ninth pilot, who was 55 years of age, was a retired Marine and Coast Guard pilot.

Levels of pertinent experience for the pilots are shown in Table 1. Approximate total rotary-wing (R/W) flight hours ranged from 2100 to 7000 (mean = 3700), and simulator hours from 15 to 360 (mean = 157). (Note,

TABLE 1. PILOT EXPERIENCE LEVELS

Pilot	R/W hours	R/W Sim hours	Sim visual	NOE hours			
				Day	Night	NVG	PNVS
1	2600	360	yes	1000	0	100	50
2	3500	50	no	100	4	4	0
3	4300	350	yes	700	0	0	75
4	3500	250	yes	500	20	0	0
5	7000	15	yes	0	0	0	0
6	2100	70	no	250	75	0	17
7	4500	75	no	400	100	300	250
8	2800	70	no	300	70	40	0
9	3000	175	yes	1000	500	500	200

however, that four pilots had no previous experience with a simulator visual system.) Four pilots also had fixed-wing experience, but only one had more than 200 hours. Except for one pilot, all had previous NOE flight experience with a mean (for these eight) of 531 daylight hours. NOE hours at night without visual aids, and using Night-Vision Goggles (NVG) and the Pilot's Night Visual Sensor (PNVS), are too varied for mean hours to be meaningful, but note that four pilots had 70 or more hours of night NOE, 40 or more NVG hours, and 50 or more PNVS hours. Pilots selected for dawn-dusk and FLIR flight conditions during the study represented pilots both with and without night, NVG, and PNVS experience.

Nature of Flights

To make the contexts meaningful for pilots during test flights, two typical mission plans were used. One was patterned after a familiarization (FAM) flight, and it provided opportunities for the pilots to become familiar with the controls while performing basic flight tasks. A second flight plan involved tactical (TAC) maneuvers and tasks. TAC flights placed special emphasis on NOE operations and tasks such as masking, pinnacle and slope operations, etc., that have been most difficult to support with simulated visual scenes, especially those generated by computer. Phases of the FAM and TAC flight plans are identified in Tables 2 and 3, respectively. Also shown for each plan are critical tasks, judgments, etc., separate by phase of flight, that should be supported by the visual system. When the word "control" appears in a task/judgment column as in "lateral control," "altitude control," etc., it refers to the adequacy of visual support to maintain or change to a desired status.

These flight plans were followed fairly closely. However, there were interruptions in a number of instances which were occasioned by needs for rest periods, equipment difficulties, and restricted availability of the system. Also, at various points during flights the pilots were asked to estimate ranges of objects and terrain characteristics (trees, targets, peaks), altitude above the ground, and ground speed. Occasions for these estimates differed from subject to subject to prevent prior knowledge from affecting them. The pilots were told the actual value after each estimate, and problems with the estimates were frequent topics of conversations among the pilots.

As mentioned earlier, there was an opportunity to obtain data regarding dawn-dusk and FLIR visual conditions. The TAC flight plan was followed for this purpose because it included tasks critical to the evaluation, especially as related to NOE flight.

Procedure

Eight pilots began with a FAM flight. The ninth pilot was available only long enough for one kind of flight, so familiarization with the system was provided in conjunction with a TAC flight. Prior to the first flight, each pilot was briefed separately, following the guide in Appendix A. Generally, the nature and purpose of the study were explained; the gaming area was described using a contour map of the actual area that was simulated; the operation of the flight controls was explained; and the flight to be completed was described. There was special emphasis on the aspects of the flight that

TABLE 2. PHASES AND TASKS/JUDGMENTS FOR FAM MISSIONS

Phase	Task/judgment
1. Takeoff to hover	Fore/aft control Lateral control Altitude control Directional orientation Clearing area
2. Hover power check	Fore/aft control Lateral control Altitude control Turns/directional orientation
3. Hovering flight	Ground speed control Track control Stopping over position Judging rate of closure
4. Normal takeoff (from hover)	Ground speed control Track control Altitude control
5. Maximum performance takeoff	Ground speed control Track control Obstacle clearance
6. Basic flight tasks	Straight & level flight Climbs & descents Turns
7. Navigate by pilotage and DR	Judging/controlling ground speed Judging/controlling altitude Pilotage features Judging range Judging bearing Identifying ETA checkpoints ETA at checkpoints
8. Traffic pattern	Altitude control Ground speed control Track control
9. Normal approach	Straight-in Descent angle control Deceleration control Track control
10. Land from hover	Fore/aft control Lateral control Descent/altitude control Judging ground contact

TABLE 3. PHASES AND TASKS/JUDGMENTS
FOR TAC MISSIONS

Phase	Task/judgment
1. Takeoff to hover	Fore/aft control Lateral control Altitude control Heading orientation
2. Hover power check	Fore/aft control Lateral control Altitude control Turn/heading orientation
3. Normal takeoff (from hover)	Ground speed control Track control Altitude control
4. Maximum performance takeoff (from ground)	Ground speed control Track control Obstacle clearance
5. Low-level flight	Ground speed control Altitude control Pilotage features Judging range Judging bearing Identifying ETA checkpoints ETA at checkpoints
6. Contour flight	Ground speed control Altitude control Obstacle clearance Pilotage features Route selection FARP/holding area selection Judging range Judging bearing Identifying ETA checkpoints ETA at checkpoints
7. NOE flight	Selecting/flying appropriate route Ground speed control Altitude control Pilotage features Judging range

(Continued)

TABLE 3. (Continued)

Phase	Task/judgment
7. NOE flight (Cont.)	Judging bearing Obstacle clearance Judging rate of closure Deceleration Mask Unmask Locating/identifying threats Locating/entering attack positions
8. Normal approach	Pattern maintenance Descent angle Deceleration Track control Terminating in hover
9. Steep approach	Pattern maintenance Descent angle Deceleration Track control Obstacle clearance Terminating in hover
10. High reconnaissance	Pattern maintenance Obstacle identification Obstacle clearance
11. Confined area operations	Pattern maintenance Identifying/clearing obstacles Landing in proper position
12. Slope operations	Pattern maintenance Identifying/clearing obstacles Landing in proper position Use of correct procedures
13. Pinnacle/ridgeline operations	Pattern maintenance Identifying/clearing obstacles Landing in proper position Use of correct procedures
14. Landing from hover	Fore/aft control Lateral control Judging altitude/touchdown Landing on preselected position

might be disconcerting, specifically, the joystick control instead of usual helicopter controls, and the simulated movement of the pilot through obstacles instead of being stopped by them. Briefings for TAC flights focused on the mission to be flown and, with aid of the (real) terrain map, the flight path to follow. After a briefing, the pilot flew the system, accompanied by one of the investigators who prompted him regarding tasks and asked for occasional estimates of range, altitude, and ground speed. The estimates were checked against data at a remote display, and the pilot was told the correct value immediately following each estimate. Pilots were also asked at times to approach a tree and state when they thought rotor contact with it would be made. (A red flash across the scene indicated actual contact.) Pilots were encouraged to avoid discomfort and fatigue by taking a break when they felt they needed one. Table 4 shows the number of sessions for each pilot and the total time he flew the system. Sessions and times are separate by FAM and TAC flights, with dawn-dusk and FLIR conditions included in the TAC data.

TABLE 4. TOTAL VSCDP FLIGHT SESSIONS AND DURATIONS

	No. of sessions		Total minutes	
Pilot	FAM	TAC	FAM	TAC
1		2		71
2 [a]	2	3	52	98
3	2	2	102	88
4 [a]	1	3	16	93
6	4	3	50	71
7	3	3	57	80
8	2		71	
9	2		16	

Note: Data for pilot no. 5 in Table 1 are omitted. He observed others for approximately 16 hours in addition to his own flight time, and an equivalent number of sessions cannot be meaningfully determined.

[a]Pilots nos. 2 and 4 had experience with the VSCDP system prior to the present study. Only participation in the study is shown here.

Upon completion of a FAM or TAC mission, each pilot was debriefed using a four-point rating scale for assessing the adequacy of visual support for the tasks and judgments listed in Tables 2 (FAM) and 3 (TAC). The rating scales were designed for use by an observer during flights. The observer was to judge difficulties experienced by the pilots and assign ratings accordingly. However, lighting inside the dome was not adequate for this purpose, and a hand-held light would have been disconcerting to the pilot. Hence, the rating scale was adapted via oral instructions so that the pilots could complete it themselves following each flight. Pilots were to rate visual support for individual tasks and judgments with a rating of 1 indicating complete inadequacy; 2 that the task (judgment) could be performed (made) but with difficulty and uncertainty; 3 that visual support was adequate with only minor difficulties; and 4 that visual support was completely adequate, giving no difficulties at all. The performance guides in Appendix B were used to help anchor the ratings.

A structured interview followed completion of the rating scale, beginning with responses and comments on the scale itself. (Spaces were provided on the rating forms for comments.) The purpose was to clarify any uncertainties that might arise in interpreting ratings and comments. Then the interview guide shown in Appendix C was followed, focusing on both strengths and weaknesses of the visual system with respect to the items in the guide. A special effort was made at this time to help the pilot distinguish between difficulties that might arise in knowing, say, how far away a tree was in meters or feet that he maneuvered around, and difficulties in avoiding the tree as a purely perceptual-motor act. Data such as these shed important light on ratings assigned to the most troublesome judgments (i.e., estimations of range, altitude, and ground speed).

In addition to these data, one of the investigators evaluated the visual system with respect to topological characteristics of visual cues. A variety of local scenes were viewed from different perspectives of altitude and directional orientation. The method for collecting these data is described in Section II in connection with the results.

II. RESULTS

The results are presented in a sequence that should help the reader follow the logic of their interpretation. Pilot ratings of the system are treated first to highlight pilot differences in evaluations and certain areas of strengths and problems in the visual system. Interview data are discussed second and related to the pilot ratings. A third subsection then presents the results of the evaluation of perceptual characteristics (cueing properties, etc.). The third set of data helps clarify the pilot ratings and information obtained during interviews. However, detailed implications of the perceptual analyses for interpreting the other data are not discussed until Section III.

PILOT RATINGS

As will be apparent, there were substantial differences among pilots in rating levels, and also among tasks. Hence, to help the reader allow for these differences, data concerning characteristics of pilots' ratings are presented first, followed by data concerning separate kinds of tasks. Then summary data are provided for different segments or phases of the FAM and TAC missions.

Characteristics of Ratings

Table 5 shows overall means and standard deviations (SDs) of ratings for each pilot and the kinds of missions he flew. (NOTE: To maintain anonymity,

TABLE 5. PILOT MEANS AND STANDARD DEVIATIONS, BY KIND OF FLIGHT

	Mean				Standard deviation			
Pilot	FAM	DL	DD	FL	FAM	DL	DD	FL
1		3.54				.56		
2	2.88	2.97	2.92		.81	.36	.28	
3	3.04	3.70			.54	.42		
4	3.32	3.56	3.34	3.42	.62	.55	.49	.52
5	2.78	2.82			.93	.63		
6	2.82		2.82	2.85	.75		.57	.57
7	3.65		3.66	3.97	.48		.75	.25
8	2.79				.45			
9	3.82				.46			

the numbers designating pilots in Table 5 and later tables do not correspond to those in Tables 1 and 4.) TAC missions are broken down according to whether they were flown under daylight (DL), dawn-dusk (DD), or FLIR (FL) conditions. On FAM flights, mean ratings for all tasks/judgments ranged from 2.78 to 3.82, and from 2.82 to 3.70 on DL TAC flights. Similar ranges obtained for DD (2.82 - 3.66) and FL (2.85 - 3.97) TAC flights, except that one pilot rated FL extremely high. Standard deviations are inversely correlated with means, as would be expected in this case. That is, the closer a mean is to the maximum rating (=4), the less variation can be present in the data. However, pilot no. 8 had a small SD, together with a low mean. In other words, this pilot gave mostly ratings of 3, with 20% or so of 2. In view of the fact that a rating of 3 implies adequate visual support for tasks overall, even the lowest mean ratings should not be discouraging. This is especially true in view of the heavy weights given particular problem areas in determining the means. That is, range, altitude, and ground-speed estimates occurred frequently as items to be rated, and they were generally rated relatively low. These problems and their effects on overall ratings will be evident later. The present purpose is only to emphasize the differing subjective metrics among the raters. Apropos this purpose, it should be noted that there is a strong correlation between mean ratings and hours of previous simulator experience, and between mean ratings and previous experience with a simulator visual system. Numerical values for these relationships cannot be given without compromising anonymity of raters, but the correlations far exceed chance expectations.

Along the line of the correlations, the pilots who gave the lowest ratings were also the ones who complained most often, and in some cases insistently, about the lack of scene realism--the absence of rocks, too few trees, etc. Interview data revealed that they often had difficulty keeping the purpose of the study in mind. They sometimes rated scene realism, not the adequacy of scenes for task support. In one case, for example, a pilot who, compared to some other pilots, had assigned relatively low ratings overall, stated that he was going to give no rating higher than 3 because "there's something about the scenes I don't like." He was asked, "But did you ever have any trouble maneuvering as you wanted to?" His answer: "Oh, no! No trouble at all." Again, there often was difficulty in keeping issues of overall scene realism separate from visual support for task performance. It was in anticipation of this problem that debrief interviews stressed difficulties and ease of perceptual-motor performance as opposed to evaluations of scene content per se.

Indices of rater reliability and agreement. In view of the differences among pilot ratings, it would be well to examine their reliabilities, and separately the extent of agreement among them. In contrast to usual treatments of these issues, reliability and agreement should be assessed separately, not lumped together as reliability. That is, reliability as usually treated in measurement theory refers only to the consistency of, in the present case, ratings as they vary around mean ratings. For example, if one pilot rated visual support for a task as 3 on the scale, but had an overall rating mean of 2, he would be perfectly consistent with another pilot who rated that task's support 4 but had an overall mean rating of 3. (For simplicity, the need to measure deviations from the mean in standard units is ignored in the example.) The reliability (i.e., consistency) of ratings for

this task would be perfect. Yet, the agreement is definitely not perfect <u>unless</u> the pilots' subjective metrics are such that 3 and 2 for the first pilot have, respectively, the same meaning as 4 and 3 for the second pilot.[1]

In the case of the present data, the usual measure of reliability, the product-moment *r* between two sets of ratings, is more or less meaningless. The problem is the restricted variability of ratings by a given pilot. The restriction arises for two reasons: the tendency for ratings to "load" on the high end of the rating scale; and the tendency of pilots to stick close to their own overall subjective metrics in assigning all ratings (e.g., the pilot cited earlier who stated he was assigning 3s because there was something about the visual scene he did not like; or the pilot who had a mean rating of 3.97 for a FL TAC flight). As variance is restricted, so does <u>co</u>variance between sets of measures--*r*--become meaningless.

Hence, it is necessary to measure reliability in a manner that does not suffer from the lack of variability of ratings. At the same time, agreement of ratings, as opposed to reliability which ignores mean differences, should be summarized by an index that does not require compound judgments involving means, SDs, and *r*s, separately. Accordingly, indices of reliability and agreement were derived as described below.

Reliability is defined as a coefficient *Cr* such that

$$Cr = 1 - \frac{Vd}{Vt}$$

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[1]This problem does not arise in reliability theory because it is assumed, and realistically so in most applications, that mean differences either do not exist or else can be accounted for in a manner that does not affect the interpretation of a coefficient of reliability, such as the product-moment correlation *r*. If one wishes to take mean differences into account, it is necessary to go beyond *r* as a measure and consider means (and standard deviations) of the various sets of measures. Mean differences <u>should</u> be considered in the present data because the meaning of a rating of 1 or 2 or 3 or 4 was supposed to anchor in ease of task performance, the inclination of some pilots to impose scene realism as an additional anchor notwithstanding. Thus, in order to clarify the interpretation of the present data, it is necessary to establish the extent to which they have reliability in the technical meaning of the term, <u>and</u> the extent to which they agree. In view of the sources of differences in ratings by pilots as just discussed, the key issue is reliability. In other words, regardless of pilots' subjective metrics, if they do not see <u>relative</u> strengths and weak-nesses in similar patterns, the rating scales can have no validity. Hence, consistency of patterns of ratings should be determined irrespective of overall mean differences in ratings among pilots. At the same time, an index of agreement is needed, if for no other reason to simplify the usual task of interpreting differences among means and standard deviations, together with indices of reliability, in assessing extent of agreement.

where Vd is the variance of differences among (in the present case) pilots' ratings, and Vt is the combined variance of the total ratings by each pilot. As explained, Vt is too restricted to be meaningful. Therefore, the task is to find a suitable measure of Vt that does not depend on the ratings provided by pilots. Because Cr is nothing else than an index of departure from a chance bivariate distribution of ratings, Vt can be determined by simply computing the variance of a chance bivariate distribution of ratings of 1 through 4. (Some pilots assigned a few fractional ratings such as 2.5 and 3.5, but they are ignored here.) In a purely chance bivariate distribution of ratings where 1, 2, 3, and 4 have equal likelihood of occurring, the variance of permutations of possible differences is exactly 2.5. Hence, Vt in the equation above was set equal to 2.5.

Cr was thus computed for pairs of pilots as 1 minus the ratio of the variance of actual differences between their ratings to 2.5. Note that in computing the variance of differences, mean differences are subtracted out, so they do not affect Cr. That is, Cr measures the consistency of patterns of ratings "corrected" for levels of ratings. Obviously, Cr cannot exceed unity; and a chance distribution of differences among ratings would result in Cr = 0. A significant negative Cr would not be interpretable in terms of reliability, as is usually the case.

A coefficient of agreement (Ca) among ratings, that is, without adjustments for mean differences, can be computed simply by substituting the mean squared difference between ratings, as opposed to their variance around the mean difference, for Vd in the above equation. Ca also has an upper limit of unity and a chance value of zero. Generally, Ca will be less than Cr because squared deviations of values from their own mean are less overall than they are from any value other than their own mean. But it is in this respect that Ca measures agreement as opposed to reliability. From interview data, it is not likely that arbitrary subjective metrics as illustrated above account for all differences between Cr and Ca. As will become evident, pilots differ in the kinds and sources of information they use while performing tasks, and a pilot who assigns a 3 for visual support in a specific instance may well not experience the same amount of support that a pilot does who assigns a 4 in the same circumstance. One pilot may be rigidly dependent on a particular scene manifestation, while another pilot may habitually evaluate what a scene has to offer in the way of information and select scene characteristics to key on accordingly. The first pilot would be more sensitive to absences of specific cue sources.

The foregoing discussion should be kept in mind in interpreting the indices for Ca and Cr in Tables 6 and 7, representing FAM and TAC flights, respectively. Cas appear above the diagonals and Crs below them. For FAM, the mean Ca was .66 and the mean Cr was .79. For TAC flights, means appear at the bottom of Table 7 for interrater ratings. Mean intrarater TAC agreement and reliability (Ca and Cr) were .90 and .91, respectively. (Intrarater data can be identified by entries in Table 7 where the same pilot number appears in two or all TAC conditions.) The conclusion is that the rating scales had high intrarater and substantial interrater reliability, and considerable interrater agreement in most cases. Also, the magnitudes of cross-condition coefficients indicate that pilots who flew more than one condition did not feel the conditions affected the usefulness of visual information (see also the means reported in Table 5).

TABLE 6. INDICES OF INTERRATER AGREEMENT (ABOVE DIAGONAL) AND RELIABILITY (BELOW DIAGONAL) ON FAM FLIGHTS

Pilot	1	2	3	4	5	6	7	8
1	--	.38	.75	.82	.71	.68	.68	.71
2	.73	--	.68	.45	.82	.46	.74	.39
3	.76	.92	--	.83	.71	.69	.77	.70
4	.82	.87	.85	--	.64	.71	.73	.69
5	.95	.83	.86	.94	--	.44	.80	.47
6	.68	.86	.70	.71	.72	--	.58	.69
7	.76	.84	.80	.84	.84	.68	--	.66
8	.71	.82	.72	.69	.77	.69	.77	--

Accuracy of Estimates

Data concerning accuracy of estimates of range, altitude, and ground speed will further clarify interpretations of data given later. These data were obtained for only seven pilots. Simulator sickness prevented one pilot from participating long enough to provide estimates, and another pilot had too much experience with the system for his estimates not to be affected by knowledge of actual simulated distances and altitudes. For range estimates, scene features (targets, trees, peaks) were selected whose actual distances varied from 750 to 3900 meters. Pilots made from 2 to 8 attempts at estimation, and except for one pilot who was generally quite accurate, during first attempts the features of concern were seen as approximately half as far away as they actually were. Estimates improved with feedback and further practice, but they were highly erratic overall.

For altitude estimates, actual simulated altitude above the ground ranged from 0 to 150 feet, and pilots made from 1 to 3 estimates. The judgments were relatively much more accurate (about 20% low) than range estimates were, and they tended to be quite accurate below 25 feet, at least to the point of 2-3 feet from touchdown. Estimates of ground speed, when actual speeds varied from 50 to 90 knots as determined by the pilots' control inputs at the times, tended to be around 20-25% low, although occasional estimates had errors of more than 50%. Most pilots made only one such estimate, though one pilot made two and another three.

TABLE 7. INDICES OF INTERPILOT AGREEMENT (ABOVE DIAGONAL) AND RELIABILITY (BELOW DIAGONAL) ON TAC FLIGHTS

	Daylight					Dawn/dusk				FLIR		
Pilot	1	2	3	4	5	2	4	6	7	4	6	7
1	--	.72	.77	.91	.65	.77	.86	.70	.77	.87	.71	.78
2	.85	--	.66	.72	.84	.96	.75	.86	.64	.69	.84	.53
3	.78	.87	--	.80	.49	.67	.80	.51	.67	.79	.49	.92
4	.91	.86	.81	--	.59	.72	.87	.67	.71	.87	.68	.79
5	.86	.85	.80	.81	--	.84	.68	.90	.45	.61	.89	.31
2	.92	.96	.91	.88	.84	--	.79	.86	.59	.74	.84	.51
4	.88	.80	.85	.89	.79	.86	--	.71	.58	.96	.72	.70
6	.91	.87	.82	.89	.90	.86	.82	--	.39	.67	.98	.33
7	.78	.83	.67	.71	.73	.81	.62	.67	--	.58	.37	.75
4	.88	.77	.82	.88	.75	.84	.96	.81	.60	--	.70	.70
6	.90	.85	.78	.88	.89	.84	.82	.98	.63	.83	--	.31
7	.85	.93	.95	.86	.84	.95	.86	.86	.79	.82	.81	--

TAC Interpilot Means

	Ca	Cr
Within conditions		
DL	.72	.84
DD	.65	.77
FL	.57	.82
Across conditions		
DL x DD	.72	.83
DL x FL	.71	.85
DD x FL	.61	.80

It is difficult to interpret these results, because no data are at hand concerning the ability of pilots, flying at helicopter altitudes and speeds, to make estimates such as these in the real world, using only out-of-window information. As some of the pilots pointed out, range estimates involving features as used here are normally arrived at with the aid of a map which is marked off in kilometers. One usually knows his own approximate position on the map, and the approximate location of a tree, target, or peak can be identified on the map. Estimates simply involve counting kilometers on a map and interpolating between kilometer lines for additional fractional values. Hence, range estimates in the real world are usually quite accurate. But again, they are rarely arrived at strictly on the basis of the out-of-window scene.

Similarly, during actual flight, altitude and airspeed indicators are available to the pilot, and no flight instrumentation of any kind was available during the VSCDP flights. As some pilots pointed out during debriefing interviews, pilots normally depend on the instruments to guide estimates that, during the test, they had to make without such guidance. A frequent exception in the real world is judging altitude just prior to touchdown when landing. Some pilots had difficulty in this task during the tests, expecting to touchdown earlier than was the case. The error was generally less than 5 feet, but even so, NOE flight is often within 5 feet of the ground, where a judgment error of this size becomes a difficulty. Examination of the VSCDP scene and interview data clarify the touchdown problem to some extent. First, the ground, including its texture, nearest the pilot tends to become blurred in the VSCDP system as touchdown is closely approached. If a pilot depends on ground characteristics nearest to him for altitude cues when landing, as some of the pilots stated they did, the VSCDP scene could not provide clear cues. A difference is illustrated by a pilot who said that he was not dependent on particular cues. Rather, he simply chose what a scene had to offer and adapted his cueing requirements accordingly. He had no touchdown difficulties during the test because, according to his explanation, he keyed on the bases of tree trunks a short distance away. (One of the investigators tried this with similar success.)

Another judgment the pilots were asked to make was the point at which a rotor would come in contact with a tree when approaching the tree slowly. No objective measure of actual distance was available, but any contact with the tree was signaled by a red flash in the scene. Data for this task were not satisfactory because the primary sources of information used by pilots in such cases, the rotor tip-path plane and effects of rotor wash on limbs, were not available. Also, as was true of the near ground at touchdown, tree foliage tended to blur instead of becoming sharper in appearance when approached closely.

Problems concerning distance, altitude, and speed judgments strongly affected ratings on tasks where these judgments are involved. In fact, it was for tasks of this nature that raters differed most markedly. It is apparent in Table 5, presented earlier, that overall rating means fall into two groups: (a) those that cluster around 3; and (b) those that are substantially higher than 3. These differences are accounted for largely on the basis of how well individual pilots could make accurate judgments of these variables. The pilots had objective feedback immediately following each estimate, so their low (and high) ratings had foundations in feedback regarding actual values.

Ratings for Separate Tasks

Ultimately, the value of the VSCDP system for attack (and other) helicopter training depends on the capabilities of the system to support given segments or phases of mission operations. Hence, to know what can be trained using the system, one must determine which mission operations are adequately supported and which are not. A later discussion addresses VSCDP support for mission segments. The present discussion provides perspective for the later one by pinpointing possible trouble areas on a more analytical basis. That is, various mission phases often require similar component tasks and judgments, so it would be well to assess possible problems with separate components before turning to the phases themselves. In turn, the problems revealed by the preceding analyses of range, altitude, and speed judgments help prepare one to interpret ratings on possible troublesome tasks.

Tables 8 and 9 summarize ratings for visual support of tasks/judgments during FAM and TAC flights, respectively. Considering means and ranges of ratings, the most troublesome areas were altitude, range, ground speed, and bearing judgments, as well as pilotage features and expected times of arrival (ETAs) at checkpoints and their accuracy. The problems with range, ground speed, and altitude judgments are already apparent, and mistakes in judgments of ground speed surely affected ETAs. Ratings for pilotage features and related dead-reckoning navigation are actually irrelevant under the circumstances. Not only was there no map of the simulated scene available, the map of the actual scene that was simulated could not be used during flight because of the low level of cockpit illumination. Furthermore, these problem tasks and judgments normally depend on flight instrumentation, none of which was available during the tests. In fact, some pilots chose not to rate items under Pilotage/DR (see Tables 2 and 3) simply because they recognized that without instrumentation, no meaningful evaluations could be made. Others apparently (from interview data) placed themselves in a hypothetical simulator having the necessary instruments, and with a suitable map available, and assigned ratings for visual support accordingly. However, at least two pilots appeared to rate the test set-up as a whole, focusing not on the visual system but on the adequacy of task support overall, including instrumentation. Nevertheless, some adjustments in personal attitudes, perceptual interpretations, or whatever, are apparent from first (FAM) flights to later (TAC) flights. Ratings increased substantially on DL TAC flights, compared with FAM flights, for pilotage features, bearing, ETA checkpoints, and checkpoint accuracy. Less dramatic increases were found for ground speed, rate of closure, and range estimates. (Changes for DD and FLIR conditions are not readily interpretable because only small subsets of the nine pilots were involved.)

Ratings for Mission Segments

Summaries of ratings for FAM and TAC segments are shown in Tables 10 and 11, respectively. For TAC maneuvers, all mean ratings were 3.00 or higher except for low-level flight (2.98 and 2.89 for DL and DD, respectively). For FAM, the primary problem concerns pilotage and DR navigation. The limited relevance of this problem was explained above. Note, however, that the relatively depressed means and the wide range of certain ratings, especially for FAM, reflect problem areas discussed earlier. Reference to Tables 2 and 3 in Section I reveal the extent to which the problem areas can affect judgments for each maneuver.

TABLE 8. SUMMARY OF RATINGS FOR FAM TASKS/JUDGMENTS

Task/judgment	Mean	Stan dev	Range
Fore/aft control	3.44	.44	3/4
Altitude	2.89	.74	1/4
Direction	3.72	.53	2/4
Lateral control	3.35	.45	2/4
Ground speed	2.65	.65	2/4
Closure speed	2.94	.53	2/4
Straight & level flight	3.62	.54	2/4
Turns	3.12	.54	2/4
Track	3.65	.50	2/4
Obstacle clearance	3.20	.73	2/4
Pilotage features	2.81	.79	2/4
Range	2.21	.75	1/3
Bearing	2.58	.73	1/3
ETA checkpoint	1.67	.94	1/3
Checkpoint accuracy	2.25	1.30	1/4
Normal approach	3.44	.68	2/4
Descent angle	3.04	.68	2/4
Decelerate	3.00	.43	2/4
Land position	3.35	.62	2/4
Ground contact	3.12	.74	2/4

TABLE 9. SUMMARY OF RATINGS FOR TACTICAL TASKS/JUDGMENTS

Task/judgment	Mean			Stan dev			Range		
	DL	DD	FL	DL	DD	FL	DL	DD	FL
Fore/aft control	3.66	3.55	3.75	.39	.50	.43	3/4	3/4	3/4
Altitude	2.85	3.00	3.00	.54	.71	.82	2/4	2/4	2/4
Direction	3.60	3.29	3.25	.37	.45	.56	3/4	3/4	2/4
Lateral control	3.60	3.27	3.38	.37	.44	.48	3/4	3/4	3/4
Ground speed	2.95	3.05	3.07	.58	.69	.80	2/4	2/4	2/4
Closure speed	3.12	3.25	3.67	.56	.83	.47	2/4	2/4	3/4
Track	3.65	3.58	3.88	.45	.49	.33	3/4	3/4	3/4
Obstacle clearance	3.47	3.30	3.47	.46	.60	.60	3/4	2/4	2/4
Route select	3.40	3.25	3.67	.58	.66	.47	2/4	2/4	3/4
Pilotage features	3.33	2.92	3.56	.65	.64	.50	2/4	2/4	3/4
Range	2.52	2.42	3.11	.83	.49	.7[illegible]	1/4	2/3	2/4
Bearing	3.23	2.77	3.19	.49	.39	.50	2/4	2/3	2/4
ETA checkpoint	2.94	3.50	4.00	.11	.50	-0-	2/4	3/4	4/4
Checkpoint accur	3.42	3.50	4.00	.45	.50	-0-	3/4	3/4	4/4
Pattern	3.51	3.32	3.54	.48	.47	.63	3/4	3/4	2/4
Descent angle	3.50	3.40	4.00	.45	.49	-0-	3/4	3/4	4/4
Decelerate	3.47	3.33	3.67	.46	.47	.47	3/4	3/4	3/4
Land position	3.32	3.33	3.50	.65	.47	.50	2/4	3/4	3/4
Terminate hover	3.45	3.60	4.00	.52	.49	-0-	2/4	3/4	4/4
Ground contact	3.20	3.00	3.50	.75	.82	.50	2/4	2/4	3/4
Correct proc	3.33	3.40	3.67	.47	.49	.47	3/4	3/4	3/4
FARP selection	3.50	3.00	3.67	.50	.71	.47	3/4	2/4	2/4
Mask	3.60	3.25	3.67	.49	.43	.47	3/4	2/4	2/4
Unmask	3.40	3.25	3.67	.80	.43	.47	2/4	2/4	2/4
Identify obstacles	3.60	3.33	3.50	.49	.47	.50	3/4	2/4	2/4
Locate/identity threats	2.40	2.25	3.17	.49	.43	.85	2/3	2/3	2/4
Locate/enter position	3.40	3.25	3.67	.49	.43	.47	3/4	3/4	3/4

TABLE 10. SUMMARY OF RATINGS FOR FAM SEGMENTS

Segment	Mean	Stan dev	Range
1. Hover	3.32	.68	1/4
2. Power check	3.27	.66	1/4
3. Hover flight	3.17	.67	2/4
4. Normal TO	3.06	.70	2/4
5. Max performance TO	3.33	.68	2/4
6. Basic flight	3.35	.59	2/4
7. Pilotage/DR	2.56	.92	1/4
8. Traffic pattern	2.97	.79	2/4
9. Normal approach	3.25	.62	2/4
10. Land	3.20	.66	2/4

INTERVIEW DATA

Several references have already been made to interview data as aids in interpreting rating data. It would now be well to organize the information systematically and relate it more generally to the rating data. As explained in Section I, interviews followed completion of each FAM and TAC flight. The discussions were structured following the outline in Appendix C. The focus was on problems encountered during flight, and perhaps to a lesser extent, on strengths of the visual system. The comments of each pilot were sifted for reactions that would be of primary interest in the evaluation. Because specific activities were discussed separately, reactions of primary interest most often reduced to only a single kind of problem if one existed. Condensed statements of perceived problems appear in Appendix D, separate by pilot and activity. The format of Appendix D follows the interview guide in Appendix C. If no problems were identified, such is indicated. Also, there are a number of allusions to aspects of scenes that the pilots thought were particularly impressive. In many cases an attempt was made to capture the attitudes of the different pilots in the condensed statements. This was done by using their phraseology, especially oft-repeated expressions such as "easy" (to perform a task), or "adequate for NOE flight." For example, "easy" (in context) often seemed to imply that nothing whatsoever was wrong so one may as well pass on to the next topic; "adequate for NOE flight" came across as a more businesslike statement of satisfaction that pertained to a particular purpose. This is not to suggest a difference in conscientiousness between the persons making

TABLE 11. SUMMARY OF RATINGS FOR TACTICAL SEGMENTS

Segment	Mean			Stan dev			Range		
	DL	DD	FL	DL	DD	FL	DL	DD	FL
1. Takeoff	3.48	3.27	3.29	.54	.57	.66	2/4	2/4	2/4
2. Power chk	3.35	3.25	3.33	.55	.56	.62	2/4	2/4	2/4
3. Norm TO	3.17	3.25	3.33	.65	.60	.67	2/4	2/4	2/4
4. Max TO	3.40	3.33	3.50	.61	.67	.76	2/4	2/4	2/4
5. Low-level	2.98	2.89	3.14	.67	.55	.64	1/4	2/4	2/4
6. Contour	3.13	3.00	3.42	.66	.71	.69	2/4	2/4	2/4
7. NOE	3.22	3.05	3.41	.66	.72	.68	2/4	2/4	2/4
8. Norm appr	3.50	3.47	3.90	.47	.50	.30	3/4	3/4	3/4
9. Steep appr	3.50	3.50	4.00	.50	.50	-0-	2/4	3/4	4/4
10. Hi recon	3.47	3.22	3.33	.50	.63	.74	3/4	2/4	2/4
11. Confined area	3.57	3.36	3.62	.54	.48	.48	2/4	3/4	3/4
12. Slope ops	3.30	3.40	3.67	.48	.49	.47	2/4	3/4	3/4
13. Pinn/ridge	3.34	3.27	3.36	.65	.44	.48	2/4	3/4	3/4
14. Land	3.45	3.33	3.50	.57	.62	.71	2/4	2/4	2/4

such statements. All pilots were mature professionals, and all in all they addressed each issue on its own merits as they saw it.

It will be noted that all pilots found much to commend in scenes, and that some pilots had few if any negative reactions. Also, there is a group of pilots who consistently reacted negatively to certain aspects of scenes, depending on the tasks being performed. This division of pilot groups corresponds closely to the two groups of overall mean ratings referred to earlier (see Table 5 and related discussion). In fact, responses of "no problems" or the equivalent were twice as frequent proportionally among the pilots who assigned the five highest overall ratings as among the four who gave the lowest overall ratings. Also, the bases for identifying problems--sizes of trees, altitude, speed, and distance judgments--are reflected clearly in Tables 8 and 9. The reflections are apparent from mean ratings on tasks, and the existence of two divergent groups is evident in the ranges of ratings shown in these two tables. Again, the correlation between ratings and identifications of problems is very high. (It is pointed out that pilot numbers as given in Appendix D do not correspond to those used in presenting rating data, nor to the numbers used in describing the pilots in Section I. With such a small group, consistent identification of data patterns could easily compromise anonymity, especially since numerous persons other than the investigators talked at length with the pilots concerning their reactions to the visual system.)

The reasons for the relative divergence of the two groups of pilots as represented in evaluations are not simple. There was evidence of differences in subjective metrics as suggested earlier, but the differences were not arbitrary. First, some pilots used everyday realism as a major criterion. This is evident, cryptically, in comments in Appendix D. The effect this can have on ratings is revealed by one pilot's low rating on a particular maneuver when his primary dissatisfaction was the failure of the aircraft (i.e., the scene) to tilt with forward thrust of the throttle, or another pilot's objection to hill tops not being rounded. It was also apparent that higher ratings by two pilots for dawn-dusk conditions were due to greater perceived realism (better rounding of hill tops was cited as one example). A second reason for differences in metrics concerned expectations. Generally, pilots who had previously flown simulators with visual systems saw fewer problems and gave higher ratings than those who had had no experience in visual simulators. (Two pilots commented specifically regarding the improvements the GE system represented.) Third, pilots varied in the nature and sources of cues they keyed on, especially in that some could select cues from what scenes had to offer while others tended to relative rigidity in cue utilization. Fourth, pilots differed in techniques of flight performance in ways other than cue utilization.

As stated, reasons for the divergence of the two levels of evaluation are not simple. Four reasons have just been identified, but the correlation with the two rating groups is less than perfect in each case. The complexity is in patterns of how these four (and certainly other) reasons became operative in a pilot's evaluations, and the pattern shifted for a given pilot depending on task. But a point of utmost importance is that no pilot had difficulty in maneuvering through scenes, nor generally any confusion regarding the characteristics of the visible terrain.

The interview data also revealed that the lack of normal instrumentation affected ratings in a few instances. The extent of the effects is not clear, however. Several pilots pointed out that they normally depend on instruments at least to help, but sometimes primarily, in making judgments they had to make through out-of-window information alone during the test. This is especially true for altitude and speed judgments. In most cases it appeared that pilots made proper allowances for the test conditions. For example, one pilot pointed out that even in descending toward a tree, he depended more on instruments to control the descent than on watching the tree. This pilot gave a fairly high rating to the scene in one such case, even though his ratings were among the lowest overall. There were exceptions to making allowances, of course. One pilot rated visual support for flying a traffic pattern quite low because, as he said, he could not judge ground speed and altitude. Normally, he would depend on instruments for these judgments.

Comments regarding lack of complete scene realism have certain relevant aspects that deserve further comment. If for no other reason, they are relevant simply because VSCDP had realism as a goal. Hence, it was important to sift comments regarding this problem fairly carefully. Numerous examples could be given, but the point can be made with only one. A fairly common reaction was that dry river beds were too straight and consistent in width. This, of course, gave no difficulty during flight. However, it was quite confusing when a tall tree stood in the middle of a river bed. Consider that (a) pilots depend on a terrain map, studied just prior to a flight, for orientation; (b) it was difficult to distinguish dry river beds from roads; (c) a tree stands in the middle of a riverbed; hence (d) the pilot does not know he is looking at a river, and wonders where he is. The explanation for the location of the tree was quite simple. The real river bed being simulated meanders, and the real tree being simulated is on the bank, not in the river. The meandering is not feasible to simulate so the bed is made straight. In such an instance the tree could be moved out of the bed.

We turn now to six problems that regularly arose for all pilots to some extent, and which appear to have good grounds. These were:

1. Appearance of trees as being too large when at a distance.

2. Difficulties in judging distance.

3. Difficulties in judging altitude.

4. Difficulties in judging ground speed.

5. Texture too flat and consistent in pattern.

6. Blurring of scene when approached very close.

These problems have been alluded to before, and it was just pointed out that instruments (and a usable map) would alleviate many reported difficulties regarding problems 2, 3, and 4. Even so, some real problems exist in scenes concerning all six items. The analysis that follows gives a foundation for identifying the problems, and Section III explains the implications of the analysis and how at least some of the problems can be alleviated. The Section

III discussion also extends to simulator sickness, which was experienced in some form by essentially every pilot.

CUEING PROPERTIES OF SCENES

The concern in this part of the evaluation was with the extent to which standard dimensions of visual perception were represented in scenes and the coherence of those that were present. The dimensions examined are listed below, and they are defined and discussed in what follows.

Aerial perspective

Parallax

Occulting

Relative motion

Relative size

Linear perspective

Texture

Textural gradient

Intensity gradient

Mushrooming

Shadows

Horizon

Scene context

No means were available for making formal measures related to these dimensions. Hence, two informal techniques were used. One was simply detailed observations of numerous portions of the scene within and outside the AOI, while the entire scene at a given location was in view. The second technique was one used by artists for centuries in evaluating depth quality of their own paintings. Restricted portions of scenes were viewed through tubes of varying diameters so as to eliminate contextual depth cues when examining particular cues, especially relative size, linear perspective, textural and intensity gradients, and relative motion. The two techniques were mixed as needed for comparisons. The person doing the evaluation had many years' experience in analyses of visual cues.

Observations were made from three locations: from the pilot's position while the observer was flying the system; from a point immediately adjacent to the pilot's position while others were flying the system; and via a remote CRT monitor while others were flying, and when the scenes were immobile (no one flying). No record was kept of the time devoted to observations of these

sorts, but they were made repeatedly during more than half the time the system was being flown during the test. The results of the observations are given below.

Aerial perspective is the distance gradient of distinctiveness of objects and terrain features. It is due not to distance per se, but to the summative effects of haze in the atmosphere which correlate with distance. During NOE flight, aerial perspective is not a particularly effective cue for distance because the pilot cannot see far enough. At low-level and contour-flight altitudes it can be effective, however.

Visibility as defined for the system was most often set at 60,000 ft for day, dawn-dusk, and night conditions, although some pilots preferred 24,000 ft for day scenes because the limits of the area simulated were too often visible with the greater visibility. However, except for the lower levels of visibility, aerial perspective was not very noticeable. This lack may well have affected some distance judgments because distant objects often appeared quite clear in scenes. Supporting this interpretation was the general view of pilots who flew under dawn-dusk conditions that these conditions had greater realism than day conditions. (There were other bases for high evaluations of dawn-dusk scenes, especially better apparent shadowing that resulted in more rounded contours. Also, as explained later in Section III, there was likely a reduction in cue conflicts.) Nonetheless, aerial perspective is not considered a difficulty with the VSCDP system. As stated, this cue is not particularly important for NOE flight, and reductions in visibility, which follows a continuous gradient in the system, can take care of any problems at higher altitudes within reasonable gaming areas. A more serious related problem, intensity gradient, is discussed below.

Parallax is the change in appearance of objects or terrain features due to changes in position (movement) of the observer relative to objects or terrain (e.g., three-dimensional contours developing as one approaches and then passes by or over an item of interest). Note that although parallax results from motion in such cases, this is not what "motion parallax" technically refers to. (Motion parallax is discussed in Section III.)

Parallax can be experienced in forward perspective when flying over an object or feature; oblique perspective when flying at an acute angle relative to the object or feature; or lateral perspective when flying a path more or less at right angles relative to the object or feature. There were no difficulties in any perspective insofar as contours of objects and terrain represented in scenes were concerned. Some pilots felt that "edges" of hills were too sharp, but any objections apparently had more to do with individual insistence on realism than with cueing values of parallax for perception of motion relative to objects and terrain. (All pilots felt that trees especially were well simulated except for size.)

Occulting refers to the interposition of objects or terrain features, or the partial or complete blocking of the view of one object or portion of the terrain by another. Static occulting gives cues for relative distances. Changes in occulting patterns with observer motion add cues for self-movement as well as provide additional distance information (i.e., rate of change in occulting patterns can be supportive of relative motion or mushrooming--see

below--as a distance or altitude cue). As with parallax, occulting has forward, oblique, and lateral perspectives (changes in altitude and forward motion produce changes in forward occulting).

There were no problems with occulting from any perspective, and regardless of altitude. Occulting was incomplete, and then just temporarily so, only when GE engineers were asked to make spur-of-the-moment changes in computer programs so as to reveal particular effects. The rapid ad hoc changes in one instance did not incorporate occulting at the outset, but this obviously is no real problem.

Relative motion is the apparent movement of stationary objects and terrain due to movement of the observer. Note that relative motion occurs with any rotational movement such as banking, turns, or changes in pitch. Also, there is an apparent movement of the terrain surface beneath the observer when climbing (terrain contraction) or descending (terrain expansion), but these altitude effects are covered later, as appropriate, under mushrooming.

Relative motion of all parts of the scene followed a realistic gradient per ground speed, track, and altitude. No discrepancies were apparent in this cue per se. However, as mentioned earlier and explained more fully in Section III, relative motion probably entered into problems of cue incongruities.

Relative size refers to the variations in size of a retinal image due to variations in distance of the object or terrain feature from the observer. As mentioned earlier, pilots reported that trees especially appeared too large at a distance. This phenomenal experience was shared by the psychologist who did the analysis of perceptual cues. Nevertheless, simulated sizes of the same trees seemed to be reasonably related to distance when they were viewed through tubes.

The problem appears one of too much size constancy on the part of perceivers. "Size constancy" refers to the tendency for a familiar object to appear the same size as it recedes from or approaches an observer. While this is happening, the size of the object's image on the retina of the eye is constantly changing, and radically so for near distances. Yet, depending on the presence of other depth cues, the object is actually experienced as unchanging in size for considerable distances. When far enough away, or when other familiar depth cues are lacking, the object actually appears smaller than "life-size." Size constancy does not hold at this point. Judgmental factors take over, usually unconsciously, and the perceiver infers size constancy rather than experiencing it directly. When viewed through tubes, far-away trees were obviously reduced in actual size, and apparently properly so. Nevertheless, size constancy as a direct perceptual phenomenon seemed to rule, although a perceiver would normally have to introduce judgmental factors at some distances simulated. Section III discusses this problem and its implications in detail, so it will not be treated further here except to say that other distance cues, especially linear perspective, relative motion, and textural gradients, depend on perceived size for coherence.

It is added, however, that many of the trees being simulated were unusually large--120 ft or more high. The pilots were not generally familiar

with such tall trees, at least as seen from helicopters, so some of their difficulties were almost certainly due to failure to take actual tree sizes into account in their perceptual judgments. That is, they were probably experiencing size constancy phenomenally because the trees did not appear small enough to require corrective judgments. Hence, the trees appeared much closer (i.e., within size-constancy range) than they actually were.

Linear perspective is the apparent convergence of more or less straight, parallel lines as distance from the observer increases. Note that linear perspective is three-dimensional. The sky and terrain appear to meet at the horizon, and the farther away a portion of level terrain is from the observer, the higher it appears (i.e., level terrain appears to slope upward from the observer, and seeing the terrain as level requires a judgmental adjustment of objective information).

When viewed in contexts of entire scenes, convergence appeared too gradual. Nonetheless, to the extent they were adequate for the task, tube views confirmed statements by a GE engineer that convergence was mathematically correct throughout scenes. Size enters into linear perspective in that the width of more or less parallel lines actually appears narrower with sufficient distance. Again, this change could be confirmed when viewing through a tube, at least for roads and dry river beds. But when viewing the whole scene, convergence seemed far too gradual. One overall problem was the lack of opportunities to represent linear perspective because of the absence of psuedo parallel lines except in valleys. Textural gradients gave additional opportunities, of course, but linear perspective seemed under-represented in them even through tubes. Often, the best linear perspective seemed to be of a quasi-vertical sort when looking down on hills from altitude.

Texture is any discriminable characteristic of a surface, including irregularities in the dimension perpendicular to the surface. Compared to CGI scenes of only a very few years ago, the VSCDP system had excellent texture of a 2-D nature. This is especially true of what appears to be shadowing integrated with the texture. Some pilots complained that the texture was too homogeneous (i.e., regular and repetitive), but this complaint appeared born more of a desire for realism than of a lack of cueing value.

All the same, there was some lack of cueing value in the VSCDP texture, and from interviews several pilots apparently had noticed it in referring to the texture as too flat. The problem has to do with a lack of 3-D texture. In the jargon of visual systems, "texture" has come to mean only color and shading modulations of a plane surface. When near the ground as in NOE flight, 3-D texture becomes important. In fact, simple upright objects such as flat inverted triangles have been found more effective in maneuvering fixed-wing aircraft close to the ground than 2-D texture is. The reason probably relates to the need for vertical depth in surfaces when judging either altitude or ground speed (see mushrooming, below). The VSCDP texture was 2-D, and further, it was not of a familiar kind. It aided in the experience of movement, and to some extent of altitude until it blurred upon close approach to the ground. But being flat and unfamiliar, the texture could not provide the discriminable cues during NOE flight that blades of grass, pebbles, etc., can.

Storage and resolution capacities limit the amount of detail that can be represented in visual scenes. Nevertheless, something might be done regarding the lack of a third dimension in texture. Instead of a plane surface, a perpendicular harmonic variation along surfaces could be introduced to break up the flatness. Also, a random component might be added to the harmonic to provide some degree of irregularity. Such provisions could be especially valuable in judging ground clearance and speed during NOE flight. In the real world, natural surface unevenness (even in deserts), rocks, etc., serve this purpose.

Textural gradient is the tendency for texture to become less differentiated (more dense) with distance from the observer. Gradients of texture are on par with linear perspective and relative size as cues to distance. From an objective standpoint, they should follow the equations for relative size and linear perspective, as well as equations for intensity gradients (see below). It was not apparent to the investigator that such was accomplished in the VSCDP system. Even when viewed through a tube, phenomenal texture did not change for considerable distances. This made distance judgments based on texture alone very difficult, even confusing. It is not clear whether the system had been programmed for continuous textural gradients. No discrete breaks were noted, but one had to contrast faraway surfaces with near ones to notice convergence and increased density. It was as though large "blocks" of areas had the same textural density patterns, while closely related indications of size and linear perspective in the same blocks showed at least some gradient qualities. In brief, local texture as discussed above appeared quite good, though it lacked a third dimension. Textural gradients did not seem adequate, however.

Intensity gradient is the decrease with distance in intensity of retinal images. From a phenomenal standpoint, the effects are a continuous darkening of objects or terrain with distance, plus a continuous reduction in hue qualities. At sufficient distances, everything appears grey, though perhaps with a bluish tint.

Intensity gradients are manipulated extensively by artists to give illusions of depth. They were not apparent at all in the VSCDP daylight condition except as might come under effects of reduced visibility on aerial perspective (intensity gradients might be confused with aerial perspective). Distant scenes were simply too bright relative to near scenes, and the colors were too rich. In fact, because of blurring of close scenes when near the ground, intensity appeared to increase with distance for a short range. This effect was apparent in photographs of scenes taken from a remote (and much brighter) CRT display. (Photographs permitted better control during comparisons of scene areas, for very small portions representing different distances could be viewed simultaneously with the rest of a scene covered.)

In view of the difficulty of getting more than a small fraction of normal daylight illumination in simulated scenes, a reluctance to reduce brightness in large portions of a FOV is understandable. Nevertheless, failure to do so can really foul up distance orientations, resulting in very complex patterns of incongruencies among cues. Hue saturation at least could be reduced.

Mushrooming is the apparent expansion or contraction (negative mushrooming) of an object or surface upon rapidly approaching it or receding from it. Mushrooming is especially apparent in the relative movement of textural qualities in an expanding or contracting circle when descending or climbing rapidly. During NOE flight, however, objects such as trees, 3-D ground irregularities, rocks, etc., give mushroom effects in horizontal flight, thus providing some of the most effective indications of higher speeds (cartoonists often employ mushrooming to the exclusion of other speed cues, and they do so very effectively).

Mushrooming, of course, follows mathematical laws of relative size, and it was represented very well in the VSCDP system for upright objects such as trees during NOE flight. However, as suggested above, the lack of ground surface irregularities such as small bumps meant no mushrooming of terrain surfaces in the horizontal perspective when flying close to the ground, say at altitudes of 5 ft or so. The belief here is that difficulties in underestimating ground speed, which were a problem until feedback had been given, would have been reduced, even removed, if mushrooming of surface irregularities could have been experienced. The density of trees in scenes was too low to provide this experience on a regular basis. The harmonic variation of ground surfaces suggested above may help in this respect.

Shadows are the variations in local brightness due to blocking of light by objects or contours of the terrain. As mentioned, texture patterns gave good shadow effects. Otherwise, with day scenes at high noon, there were not many opportunities to have shadows. Those that were provided (e.g., underneath trees) appeared adequate, but of course shadows of this sort do not aid distance or altitude judgments. Pilots felt that shadowing was adequate nevertheless. Instead of shadows, perhaps attention should be devoted to intensity gradients as discussed above, which appear to have much in common with shadows from an engineering standpoint. Intensity gradients function regardless of sun position, given any usable amount of overall illumination. They are also more important than shadows for judging distances and bringing overall cue coherence to scenes.

Horizon is the distant apparent convergence of the sky and terrain, given adequate visibility. A horizon is usually not visible during NOE flight, so it is not a major concern in the VSCDP system. Nevertheless, when it is visible, it sometimes has a considerable impact on distance judgments because of its contextual value (see discussion in Section III of individual asymptotes or limits in judging distances). At other than NOE altitudes, horizon effects were restricted due to the limited area represented in the GE breadboard model. Such would not be the case in operational models, and no difficulties with horizons are anticipated.

Scene context, for present purposes, refers to the comprehensiveness of cues from different sources from which a phenomenal perceptual reality can be constructed. This topic can be treated better and more fully in a discussion of the findings as a whole. Comments regarding scene contexts thus appear in Section III. At present, it is mentioned only that VSCDP scenes were rich in overall cue value. Within the limits of monocular 2-D displays, problems appear to be primarily in lack of coherence of cues in a phenomenal, as opposed to mathematical, sense.

III. DISCUSSION AND CONCLUSIONS

PM TRADE's effort to advance the state of the art in visual simulation has been successful insofar as the GE system is concerned. Although further development of the system is clearly indicated by the results of the evaluation reported here, it is evident that GE's system as a whole can meet the general design goal of providing visual support for training Army helicopter combat operations in simulators. Numerical ratings of numerous aspects of visual support for separate tasks, which were made by experienced attack-helicopter pilots, ranged from adequate to truly superior overall. The ratings were confirmed by extensive interview data which showed signal strengths of the GE system. The interview data also identified problems in the simulation which, among other things, resulted in relatively low numerical ratings for certain aspects of visual support during flight.

Strengths and problems in the simulation were discussed in Section II in connection with specific findings. It was pointed out that some problems as perceived by pilots who aided in the evaluation were due to occasional expectations on the part of the pilots that scenes should be realistic in detail. (All pilots were impressed by overall realism of scenes.) Discussions in Section II discounted criticisms of scenes that appeared to arise only from implicit or explicit demands for realism. As was pointed out, <u>no</u> pilot had difficulty maneuvering through scenes, although there were occasions when scene shortcomings resulted in adoption of somewhat unnatural strategies. For example, one pilot reported that in descending into a confined area he avoided obstacles late in the descent by structuring the entire descent at the outset; blurring of near obstacles (and the lack of a usable rotor-tip plane and rotor wash) late in the descent prevented use of near cues for control adjustments. A rotor-tip plane can be provided quite easily, and it will be. Blurring of near surfaces is more difficult to correct. Even so, such problems would not seriously hamper use of the system for most aspects of combat helicopter training.

Other problems were identified that were not due to expectations of realism alone. Furthermore, they pertain to perceptual processes that can differ substantially from those involved in maneuvering around near obstacles. For a pertinent but seemingly superficial example, it is one thing to judge the distance of an object on a desk as part of an act of reaching for it and picking it up. Making a metric judgment of its distance is quite a different matter. Cues differ for the two kinds of tasks, as well as the perceptual-cognitive processing involved. Although many of the more serious problems with the GE system can perhaps be handled through tweaking, it will further VSCDP's goal of developing superior visual systems if they are examined in some detail. Such is the purpose of the discussion in this section.

Ostensibly, the problems were:

1. Distant trees appeared too large.

2. Distance judgments were difficult.

3. Altitude judgments were difficult.

4. Ground speed judgments were difficult.

5. Texture appeared too flat and consistent in pattern.

6. Surfaces blurred when approached closely.

7. Some form of simulator sickness appeared often.

As pointed out in previous discussions, the first four problems seem to derive from a common base, and the fifth problem, textural perspective, probably has aspects in common with the first four. The first four problems are addressed at length below. The fifth and sixth problems were discussed in Section II and will not be treated further. Simulator sickness, the last problem above, is also discussed at some length. This problem is becoming critical, because regardless of whether judgments of size, distance, altitude, and speed can be made realistically accurate, a simulator cannot be used to train pilots if it makes them sick.

The title of a recent conference presentation is thought-provoking in this respect: "Simulator sickness: Is it the price of advances in simulator technology?"[1] Only an abstract of the presentation is available, and the authors of the report may or may not agree with the way the idea is extrapolated below. In fact, it will take a while to get to simulator sickness, because possible difficulties resulting from scene improvements need to be examined in their own right. The discussion develops the point that good, but less than perfect simulation of the visual environment must account for a class of variables that did not even have to be considered in the cartoon-like scenes that until very recently were state-of-the-art in visual simulation. The focus of the discussion is on the nature of perceived reality as opposed to the mathematical abstraction of reality that characterizes designs of visual systems. The arguments are necessarily technical in nature. They address basic issues which, apparently, have not been considered heretofore in the design of visual systems. The arguments are only summary in nature, however. They are drawn from developmental, as yet unpublished work by one of the present authors. The need to develop full implications of the points made will be apparent, for they apply clearly to most of the critical problems listed above.

The discussions are grouped under three major heads, perception vs. reality, illusions, and simulator sickness. Finally, there is a summary statement of conclusions drawn from the evaluation of the GE VSCDP system.

PERCEPTION VS. REALITY

As stated, this discussion is summary in nature. Only principal considerations are mentioned, together with indications of their mutual

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[1] Lilienthal, M. G., Frank, L. E., Kennedy, R. S., & Merkle, P. J. Proceedings of the Third Symposium on Aviation Psychology. Columbus, OH: 22-25 April 1985.

implications. The arguments have minimal documentation here. In all instances, however, the arguments derive from what was discovered in experiments up to 150 years or so ago, and from much earlier logical analyses of factors in simulating depth. With later refinements, these discoveries have stood the test of time well. The point to bear in mind is that the structure of what is perceived does not bear a one-to-one correspondence to the objective stimuli on which perceptual reality is based. To use a common expression in the study of perception, one does not perceive reality so much as one bets on what it is. Almost any everyday scene is rife with conflicting cues. Even the cues that do not conflict in and of themselves provide only vague perceptual metrics and structures. A perceiver learns to identify drivers for structuring the visual environment. Drivers are those cues which are used to calibrate perceptual metrics of all other cues so as to impose coherence on perception. Size constancy and linear perspective are commonly used as drivers in depth perception. But note that as interview data showed, pilots differed with respect to drivers. More important from a simulation standpoint, they also differed in the extent they could select drivers from what scenes had to offer. Some pilots were comparatively rigid in this respect, depending on habitual cue sources. Other pilots searched scenes until they found a cue source they could depend on for the task at hand. In either case perhaps, sizes of objects or linear perspective may have been the ultimate topological characteristic chosen as a driver. The difference among pilots would then be due to their inclination and ability to sift cue sources for judgments of size and linear perspective until sources were found that gave reasonable bases for calibrating all cues. (It appeared from interviews that coherent calibration sometimes called for deliberately blocking out certain aspects of scenes because of unresolvable conflicts.) It is suggested later that differences among pilots can be reduced by manipulating certain drivers asymptotically.

Related to problems of cue calibration, an interim report evaluating the GE system[1] and a report of more general concern[2] emphasized that advances in realistic simulations of visual scenes have suffered because, in effect, for every advancement in scene simulation, the likelihood increases that something of significance has been left out. When trees are shown as two-dimensional triangles as in cartoon-like scenes of yesterday, there are no three-dimensional contours to be integrated with other factors in constructing a coherent perceptual reality. A tree could be ignored once it was identified as such and avoided or whatever during flight. Lacking depth, the plane-figured tree had no significant value as a temporal basis or metric in evaluating (i.e., interpreting) other scene characteristics, nor did information regarding the tree have to be calibrated. Pilots flying simulators in "the old days" could adopt an attitude of "let's pretend" and not worry about two-dimensional trees. Problems of overall scene coherence were minimal simply

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[1] Spears, W. D., & Corley, W. E. Preliminary evaluation of a visual system in its support of simulated helicopter flight (Seville Draft Report). Irving, TX: Seville Training Systems, November 1985.

[2] Spears, W. D., & Isley, R. N. Implications of current technology for aircrew training in the future. (Seville Tech. Rpt. TR-85-35). Irving, TX: Seville Training System, January 1986.

because "let's pretend" pervaded utilization of external visual cues, flat trees in particular. A pilot could pick and choose what he paid attention to. On the other hand, the contours of realistic trees and terrain, especially as parallax varies during movement relative to it, must certainly become quasi metrics to contend with in judging speed and distances of other objects. If nothing else, a three-dimensional tree so richly represented as in the GE system more or less clamors for attention. It cannot be ignored, nor can its value as a quasi metric be easily forgotten. So the answer to the question raised by Lilienthal et al., is simulator sickness a result of improved visual simulation? could well be yes. Before deciding so definitely, however, one needs to look analytically at some differences between perception and the objective world.

Size Constancy

The inclination to see an object as being the same size within a considerable range of distances is called "size constancy." Within these distances, the actual size of the immediate stimulus, the size of the object's image on the retina of the eye, can vary radically. Nevertheless, perceived size can remain constant, and it is equivalent to that of the object when it is at minimal viewing range. It is important to note that we speak of the experienced phenomenal size, <u>not</u> an inferred or judged size. For example, some pilots insisted that trees did not change in size through considerable ranges of distance as the trees were being approached. Tube views revealed clearly that the trees <u>did</u> change in size. Size constancy dominated the pilots' perception. That is, trees were perceived <u>reflexively</u> as actually not changing in size as they approached or receded in the visual field. The effects of automatic adjustments that maintain size constancy are often evident in photographs taken by inexperienced photographers. They stand too far away from the object of interest. The photographers "see" the object in true "life size," even when looking through a restrictive viewing lens; but the camera relentlessly follows laws of the projective geometry of visual angles, resulting in the object of interest being disappointingly small in the final print. In laboratory studies, size constancy in the reflexive sense has been found to hold for distances of more than 130 ft. Beyond a certain distance, one becomes aware of the relative smallness of objects and introduces judgment so as to infer actual sizes. Although automatic if not reflexive in nature because of years of practice, size judgments can be distinguished from size constancy in controlled laboratory conditions. For an obvious example of the difference, one study found that judged sizes of <u>un</u>familiar objects were realistic even when, some 2,350 ft away, the objects were barely visible.

Size constancy was used in Section II as a basis for commonality of difficulties in judging sizes, distances, altitude, and ground speed. Other concepts might have been used as a common explanation--linear perspective, for example, as illustrated later. However, size constancy was convenient for this purpose because of the frequent complaints by pilots that distant trees appeared too large, and in spite of apparent proper scaling of trees with distance when they were viewed in isolation through tubes. One might normally expect that relative (i.e., retinal) size would govern linear perspective. If size constancy in width of parallel lines as opposed to judgments of width leads a perceiver to discount reflexively an otherwise apparent partial convergence of the lines with distance, linear perspective ceases to be a

reliable cue for distance. Furthermore, relative size cannot be depended on either because of inherent perceptual conflicts. For example, one pilot believed strongly that the banks of a dry river bed, which as simulated were objectively parallel, did not "come together" (converge) with distance. Views through tubes showed proper convergence. Size constancy pertaining to the distant width of the river bed apparently overruled objective convergence. Add to this confusion the extreme size constancy of trees characteristic of the same pilot (and others). The result is a mutual confusion of linear perspective and size constancy. Neither can be depended on as a basis for calibrating the other, nor for that matter, any other cue source. In turn, if distance perceptions are fouled up, rate of movement with respect to distances--ground speed--cannot be perceived accurately; nor can altitude, which is perceived as a function of distance cues encompassing the entire visual scene.

Size constancy varies with a host of contextual factors which govern the distances within which it is a reflexive phenomenal experience. One important factor is familiarity with the object being viewed. The more familiar the object, the farther the distance away it will be seen phenomenally as unchanging in size. On the other hand and perhaps in seeming contradiction, the less familiar an object, the greater the likelihood it will be judged as being the same size as other similarly appearing objects regardless of the latters' distances. The contradiction dissolves in the distinction between size constancy and judged size. In the absence of correlative information to the contrary, the more similar the characteristics of objects, the greater is the reflexive tendency to assume comparable sizes. This assumption will be fed into the perceptual processing of distance. If two trees actually differ in size, and if the larger tree is farther away, confusion regarding distance necessarily results: The more distant tree is too large for its distance relative to the nearer tree of the (assumed) same actual size. This problem is worsened when the two trees are constructed from the same universal features as in GE's visual system, and they are constructed by the same algorithm. What is to tell the perceiver, reflexively, that the two structurally similar trees actually differ in size when the natural inclination is to accept uncritically an equivalence of size until dissimilarity is established by other means? ("Other means" often involve close inspection in everyday life.) An obvious answer to this question is, what tells a person in real life that two trees differ in size? The temporizing nature of the counter-question will become evident.

Role of Context in Perception

Overall stimulus contexts have varied and profound impacts on perception. Just identifying roles of contexts in summary fashion would require a lengthy treatise. The discussion that follows attempts to identify not so much the roles of contexts as to point to their complexity. It attempts to show that the value of cue parameters in the perception of depth cannot be meaningfully assessed--nor simulated--without regard to possible driving cues and to other cue parameters that normally function in given situations. It explains that advances in visual simulation have probably increased difficulties arising from too much size constancy simply because size constancy increases with scene richness. Building on this introduction, later subsections illustrate how contextual patterns can more or less impose three-dimensionality on

two-dimensional representations through a subjective "projective geometry" of perception, as opposed to the projective geometry of stimulus reality. However, the discussion goes only as far as deemed necessary to explain why designers of visual systems should examine the nature and geometry of perception qua perception in addition to mathematical descriptions of objective reality.

In line with the earlier use of size constancy as an integrative concept, Figure 1 illustrates the role of contextual depth cues in size constancy. The figure is a somewhat simplified representation of findings by Holway and Boring[1] as supplemented by those of Lichten and Lurie.[2] Viewing distances ranged from 10 to 130 feet. Sizes of target objects as perceived were compared with that of a standard similar near object of "known" distance. The objects being viewed, whether targets or the comparative standard, were discs of light adjusted in size to provide a constant visual angle at all distances. The experimental subjects had no independent knowledge of actual disc sizes. The diagonal solid line in Figure 1 represents what subjects would report sizes of target objects to be, relative to the standard, if size constancy completely determined perceived sizes. The horizontal solid line near the bottom of the figure shows what perceived sizes would be if subjects depended entirely on sizes of retinal images (actually, visual angles as quantified in the reports). The dashed lines illustrate reported perceived sizes relative to the standard for varying amounts of contextual distance cues. Up to the distance of 130 ft or so used in the experiments, size constancy ruled perceptions when ample contextual cues were present. As suggested in Figure 1, size constancy overcompensated slightly for distance when the context was rich with distance cues; but when all contextual cues were essentially eliminated, perceived sizes of targets had a more or less one-to-one correspondence with (constant) size of retinal image (i.e., relative size as defined in Section II). With varying amounts of contextual cues, as represented by the three intermediate dashed lines, perceived sizes as imposed by an observer became compromises between size constancy and magnitude of retinal images.

Unfortunately from the standpoint of visual system engineering, but fortunately for adapting to the real world on most occasions, perceptual constancy is an attribute of a number of sources of cues. Reflexive brightness constancy, for example, leads a perceiver to assume that, in the absence of information to the contrary, all similar-appearing objects have the same brightness. In such cases, experience leads one to believe reflexively that the dimmer an object appears, the farther away it must be. As pointed out in Section II, the GE system did not have an adequate intensity gradient. The natural inclination to adjust for brightness constancy had to lead to overall confusion in perceptions of distance. Other perceptual constancies, such as for shape and configuration (constancies also occur in sensory modes other than vision), compound the problem, and in highly complex ways. Just the

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[1]Holway, A. H., & Boring, E. G. Determiners of apparent visual size with distance variant. American Journal of Psychology, 1941, 54, 21-37.

[2]Lichten, W., & Lurie, S. A new technique for the study of perceived size. American Journal of Psychology, 1950, 63, 281-282.

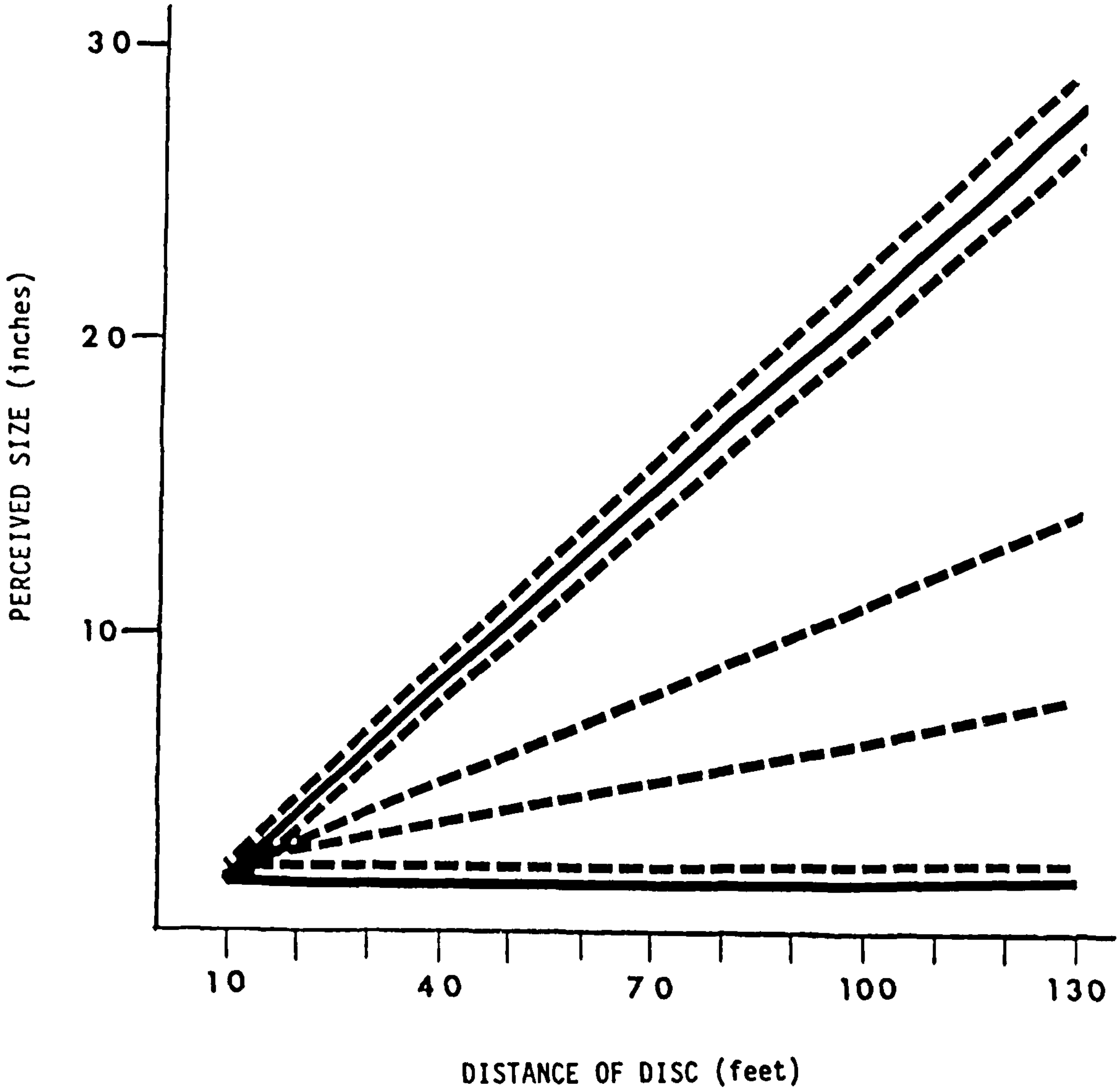

FIGURE 1. Effects of context on perceived size.

(Solid diagonal line represents perfect size constancy; solid horizontal line represents perceived size if only retinal image determined perceptions. Dashed lines are perceived sizes relative to the standard.)

interactions of size constancy, linear perspective, and brightness constancy are enough to give pause to an engineer who designs a CGI system for a flight simulator. As they become manifest in visual systems that no longer permit a pilot to play "let's pretend," these variables alone make pertinent the question, what has been left out? The answer cannot be a resort to projective geometries of terrains as can be described, imperfectly, in terms of relatively independent characteristics of cues and their sources. The engineer must seek a logic for design that allows for trade-offs of cues by perceivers. At the same time, the engineer must avoid the impossible job of tracing the complexities of cue interactions and their variations among individual perceivers. The strategy might well be to focus on driving cues that most pilots use, and to employ techniques for manipulating them that yield the desired results. Such a strategy is suggested below. It approaches the problem, ultimately, through linear perspective, not size constancy. The strategy may or may not take care of simulator sickness. However, to the extent that simulator sickness results from a lack of coherent calibration of visual cues, and to the extent the strategy might resolve problems of this sort, simulator sickness is also addressed. Nevertheless, as explained later, the problem of simulator sickness requires a perspective that goes beyond visual cueing alone.

A Size-distance Function

As explained earlier, difficulties in judging distances of objects, altitude, and ground speed had a common basis. Size constancy was used to integrate these separate problems intuitively. A more systematic formulation is needed of how these problems tie together. A simple function is given first that relates the height h of a retinal image to the actual height H of an object being viewed. An adaptation of this equation that can incorporate size constancy and contextual distance cues then reveals the difference between the projective geometries of perceptual as opposed to objective reality.

Due to the reversal of images by the lens of the eye, lines of sight projected from, say, the top and bottom of an object to the eye cross in the lens, resulting in two similar triangles as illustrated in Figure 2. Therefore, using symbols in the figure, the ratio h/d equals the ratio H/D, where d and D are, respectively, distance from lens to retina and distance from lens to object. The distance d is constant, and it can be considered a unit distance (it is actually an inch or so), which gives

$$h = \frac{H}{D} \tag{1}$$

where D is in units of d. This equation represents a mathematical projection of retinal size as should normally govern relative sizes in scenes simulated via angular projections. In fact, equation (1) describes perceived sizes of objects when all other distance cues, including object familiarity, are eliminated. It is the basis for the horizontal solid line in Figure 1 shown earlier, and for the finding by Lichten and Lurie represented in Figure 1 showing that perceived size corresponds to retinal size when all other factors are controlled.

Some adjustments in equation (1) will account for certain contextual effects. Specifically, from the standpoint of perception, the operative value

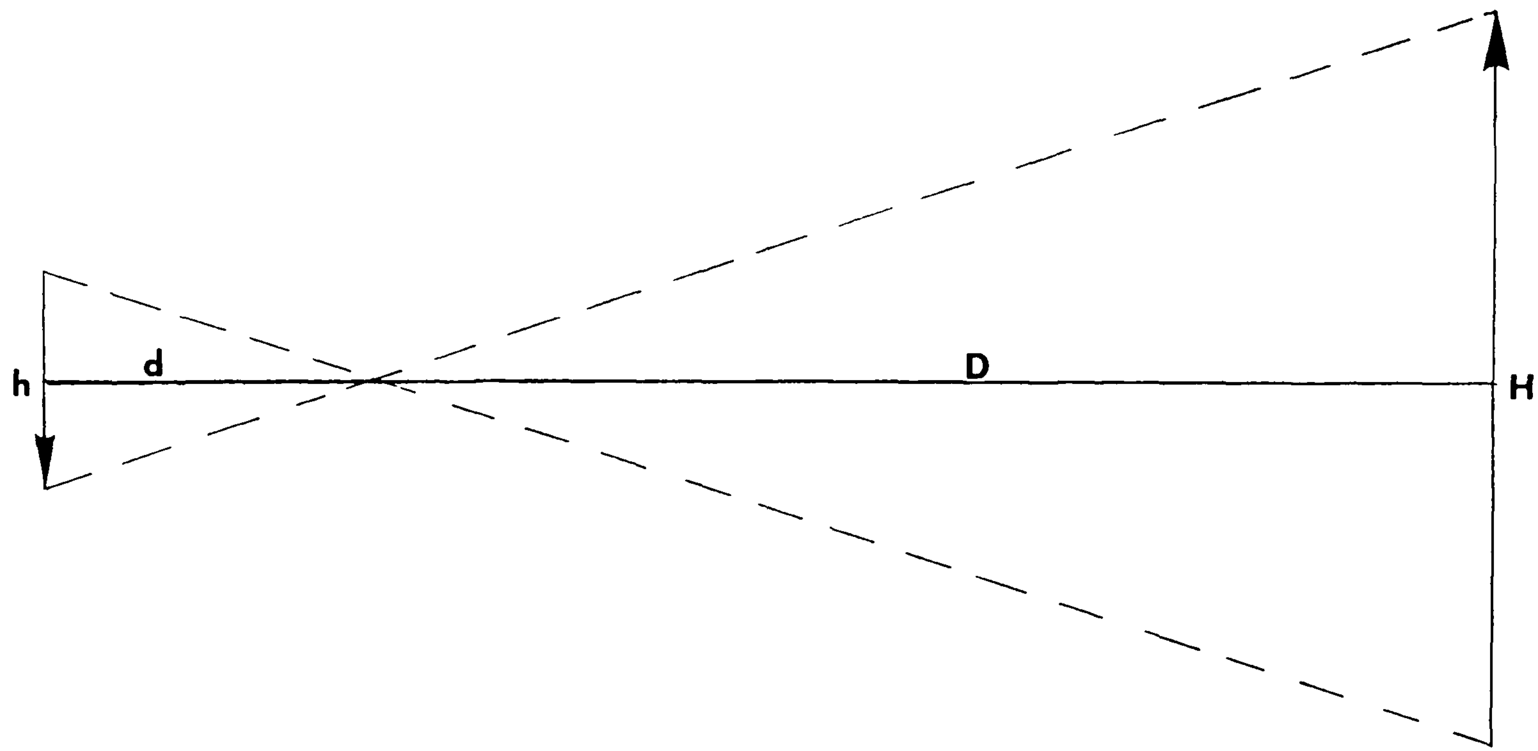

FIGURE 2. Projected size of an object on the retina of the eye.

(Object is of height _H_ and distance _D_ from lens, yielding an inverted image of height _h_ and distance _d_ from lens.)

of D in equation (1) is not objective distance, but perceived distance as determined by contextual distance cues--linear perspective, occulting, textural and intensity gradients, etc.--plus the tendency for size constancy as governed by, among other things, an implicit assumption that all similar objects are the same actual size. Hence, to project a perceptual reality as opposed to an objective reality, one must determine the effects of contextual (and of purely perceptual processing) factors on perceived distance. Perceived distance, call it D', then replaces D in equation (1), and the perceived height h' can become a dependent variable, a function of D', not a physiological given as h is. If $D' < D$, for example, perceived height $h' > h$, which was a common experience among the pilots insofar as trees were concerned, and to some extent the inequality held for the width of river beds that were supposed to converge. With the substitution of empirical measures of perceived height h' for h, and independently determined measures of perceived distance D' for D, equation (1) holds at least approximately.

Subjective Distance Asymptotes

It is a tedious process to trace contextual effects on h' and D', even for static scenes under controlled circumstances; and when momentarily viable dynamic scene relationships must prevail as in flight simulation, the computer processing requirements involved would become impractical, even if the mathematical models involved were tractable (and if enough were known about contextual variables to construct mathematical models). Perhaps the problem can be addressed more easily. Emerging visual systems have considerable realism. One may assume that as scenes increase in realism, the number of contextual distance cues can increase to a near-asymptotic degree insofar as nonredundancy is concerned. Hence, resolution of the simulation problem may involve no more than identifying a function that relates perceived distance D' to actual distance D in the stimulus-rich real world. A candidate function of this nature is available. The function can identify subjective asymptotes against which perceived distances are scaled. Given this knowledge, adapting scene simulations to desired perceptions of size and distance--and hence of altitude and speed--becomes a matter of knowing how distance is scaled relative to subjective asymptotes, and then manipulating the asymptotes. This, too, has precedence. As will be seen shortly, the revolutionary advances in representing depth in paintings that began in the fifteenth century was a matter of manipulating asymptotes, and manipulating them in ways that often had no objective counterparts per se in the paintings!

The candidate function for identifying asymptotes was developed from experiments and analyses by Gilinsky.[1] An observer stood, for example, at one end of an 80-ft archery range and directed the experimenter in marking off successive distances that appeared (i.e., were perceived) to be in equal units. (Note the real-world context, plus familiarity with a target object--the experimenter--which fosters natural inclinations to size constancy in

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[1] Gilinsky, A. S. Perceived size and distance in visual space. Psychological Review, 1951, 58, 460-482.

judgments.) Reported perceived distances, D', closely fit the equation

$$\frac{D'}{D} = \frac{A}{A + D} \tag{2}$$

where D is the actual distance and A is the subjective asymptote of possible distances within the limits adopted by the observer in the real-world context. (Expectations derived from the overall experimental conditions helps define the subjective limits.) For one experiment using the archery range, A was found to be about 94 ft. Variations in where observations were made and in experimental conditions resulted in subjective distance asymptotes ranging from 50 to 300 ft. Equation (2) held in each instance, with A being determined by fitting the function to D and D' measures.

It was pointed out in Section II that horizons can have significant value as contexts for distance judgments. Horizons provide an objective limit against which distances can be scaled. Indeed, subjective asymptotes as found by Gilinsky have been termed, in effect, subjective horizons of "infinite distance."[1] A more context-oriented description, "effective contextual limit," for example, might be more descriptive of a subjective asymptote. But whatever it may be called, the important fact is that it varies with stimulus context and with the perceiver's expectations.

Vanishing Points

We turn now to how subjective distance asymptotes might be manipulated in simulations. The issue can become quite involved, especially when dealing with curved surfaces, but it will be treated here in its simplest form. Beginning in the fifteenth century, artists began achieving greater depth in paintings, and realistically so, than can be found in most modern photographs. They do so by introducing so-called vanishing points. To see the effects of vanishing points on perceived depth, one need only contrast pre-fifteenth century paintings with later work beginning with Leonardo da Vinci (1452-1519), Albrecht Dürer (1471-1528), and Piero della Francesca (1420-1492). Dürer even made several woodcuts illustrating how to identify vanishing points through projective geometry.[2] The principle is illustrated in Figure 3. A rectangular surface, shown upright in A in Figure 3, is viewed as lying flat before the observer (B in Figure 3), foreshortened to account for linear perspective. The illusion of depth can be seen quite readily in B. Notice, however, that C is not seen in three dimensions, at least not as readily, even though C is the same size and shape as B. C is too close to the top of the page for the observer to project, on his own, a vanishing point. A vanishing point for B is where the sides would converge if they were extended. To control for the influence of the upright A on B, simply cover A and note that B still has depth. Or, cover the top portion of the figure so as to eliminate

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[1]Woodworth, R. S., & Schlosberg, H. Experimental Psychology (rev.). New York: Hold, 1954, p.482.

[2]For an excellent discussion of how these men used vanishing points, see Chapter 10 in M. Kline, Mathematics for the liberal arts. Reading, MA: Addison Wesley, 1967. This book was reprinted under the title Mathematics for the nonmathematician. New York: Dover Publications, 1985.

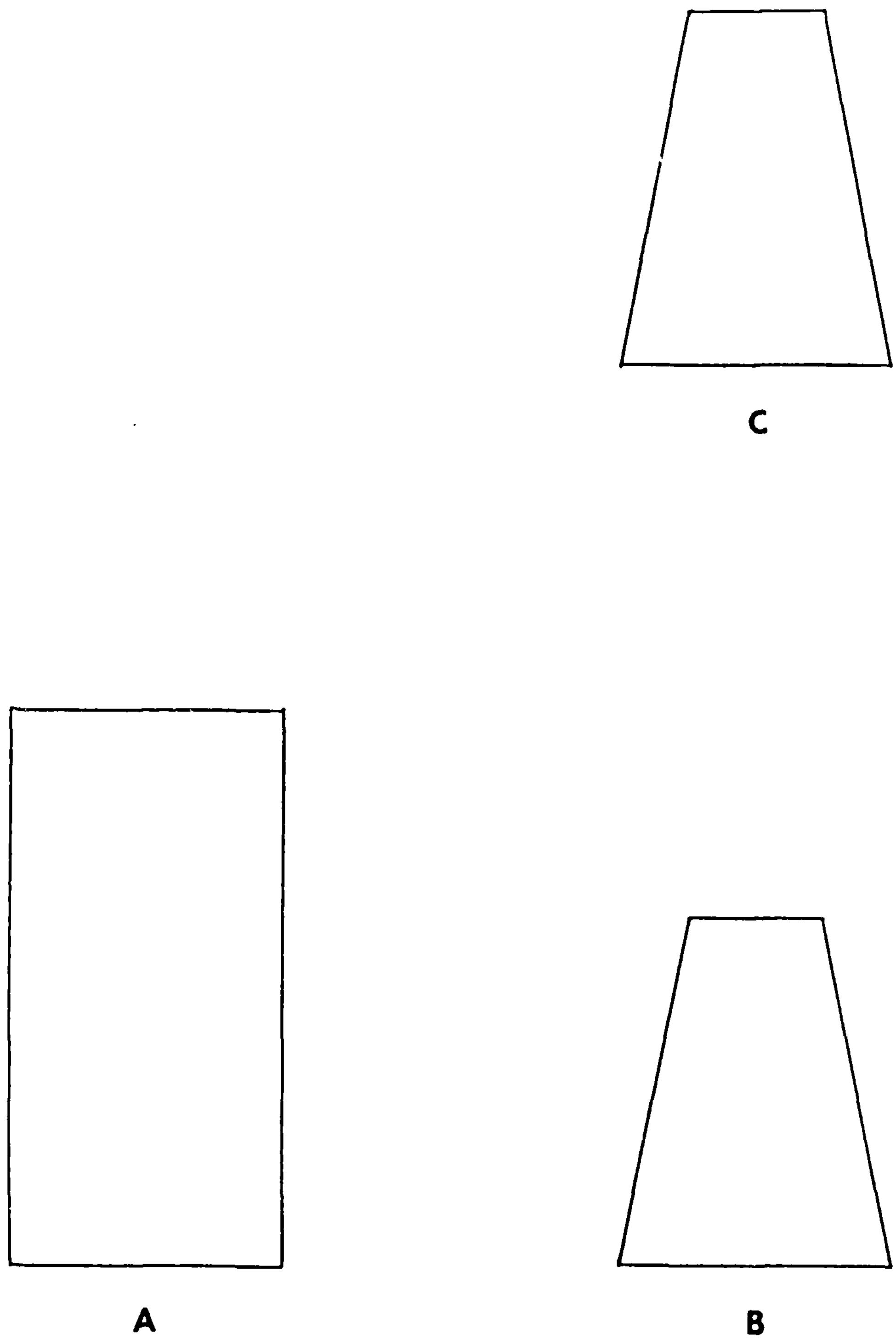

FIGURE 3. Effect of a vanishing point on linear perspective.

B's vanishing point and note B then appears as an upright two-dimensional figure.

Geometric projections of the actual object, the solid lines in B of Figure 3, may be represented accurately in a simulated visual scene. However, as recognized by da Vinci et al., the illusion of true depth depends on the observer's being able to project, on his own if necessary, a vanishing point in linear perspective. The vanishing point as such need not be an objective component of the scene, as it is not in B of Figure 3. On the other hand, if the scene is such as to prevent this natural aspect of perceptual projection as in C, confusions in distance judgments can be expected. In the case of apparent failure in convergence of river banks in the GE VSCDP system, the river seemed to run straight into a steep ridge running at a right angle to the river. The nearly vertical ridge filled the AOI scene to the upper limit. No vanishing point could be projected beyond (and hence above as in Figure 3-B) the apparent end of the river because the ridge blocked it out. (The river actually turned sharply at this point and continued around a ridge that was parallel to the visible portion of the river, but the turn could not be seen until approached fairly closely. A meander to the left prior to turning to the right around the parallel ridge might have solved the problem.) In other instances, possible provisions for vanishing points were vitiated by a restricted AOI. The psychologist who evaluated the topological cueing properties of scenes found that at low altitudes he had to keep manipulating the AOI up and down for distance perspective. (As would be expected, the problem varied with altitude.)

In brief, judgments of actual distances depend in a systematic way on subjective distance asymptotes. Subjective asymptotes vary with contextual cues that establish a referent horizon, or "infinity," where parallel lines converge. Unless an operative FOV--an AOI, for example--permits perceptual projection to a vanishing point, subjective distance asymptotes are restricted, resulting in underestimates of distances and hence general confusion in a variety of judgments that depend on distance for a basis such as estimates of altitude and ground speed. Perceived size thus is akilter as evident from equation (1) when h' is computed using D'.

Klinel[1] also illustrated how a vanishing point radiates back to the observer, permitting the observer to impose his personal three-dimensional linear perspective on a scene as a whole. Artists foster three-dimensional linear perspective by arrangements of scene contents, but perceivers apparently construct such three-dimensional perspective out of whatever the real world offers.

No wonder the pilots who assisted in this evaluation found dawn-dusk and night scenes more realistic than day scenes. Life-long experiences with occasional restricted visibility lead one to expect less in scene richness when such visual restrictions exist. Thus, one learns early in life to depend less on vanishing points and other contextual cues under these conditions. It is pointed out again that pilots had no difficulty maneuvering in the near

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[1] Op. cit., 1967.

environment (excepting problems caused by blurring of near scenes). As with dawn-dusk and night, as well as with FLIR conditions, during the day one maneuvers a helicopter with respect to near objects without regard to judgments of distances of remote characteristics of scenes. Focal as opposed to contextual cues dominate in conditions of limited visibility, and in dealing with near objects under any visibility conditions.[1]

It is recognized that artists are free to construct static scenes as they wish, and that designers of dynamic visual systems have considerably less freedom, especially when restricted by requirements to simulate a particular real terrain as closely as feasible. The argument here is that designers of visual systems should be permitted artistic license to the extent necessary for observers to experience realistic depth. By manipulating scene contents, illusions of true depth can be created even in scenes that must satisfy dynamic requirements. This point is especially significant in view of the emerging technology of using actual sequential photographs of terrain stored on video discs, whose dynamics in visual systems are then controlled by computers (e.g., Computer Animated Photographic Terrain View, or CAPTV). It is easy to assume that photographs of actual terrain are prima facie realistic, and thus the epitome in good visual simulation. However, photographs are still two-dimensional representations of three-dimensional manifolds, and they usually leave a lot out. Unless the cameraman is an expert in projective geometry of perception, depth relations in, say, CAPTV scenes will be as anemic as they are in slides tourists are wont to impose on their friends. For a realisitic experience of depth, view a competent painting, or at least slides taken by a competent professional photographer.

Summary and Implications

The preceding discussion illustrated the difference between a projective geometry of visual perception and a projective geometry of objective stimuli on which perception is based. It was explained that the physical equation relating sizes of retinal images to actual distances of objects did not hold for either perceived sizes or perceived distances. However, the equation will hold under a variety of circumstances if actual retinal size h is replaced by perceived size h', and actual distance D by perceived distance D'. The equation then becomes

$$h' = \frac{H}{D'}. \tag{3}$$

It was further suggested that subjective scales for D' be manipulated in scenes, through vanishing points, for example, so as to bring h' to taw. By approaching the problem asymptotically, individual differences in D' can perhaps be reduced. It was not mentioned, however, that size constancy may

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[1]See Leibowitz, H. W., & Owens, D. A. We drive by night. Psychology Today, January, 1986, p.54-58. They use the term "ambient" perception instead of contextual cues, but the difference is only in terminology. As they point out, focal perception as in dealing with objects is retained under limited visibility, but ambient perception is radically reduced.

still be too strong on occasion, especially in perceptually rich scenes. In such a case, tweaking of a simulated $\underline{H}$ may still be necessary.

At any rate, equation (3) should give a good first approximation of scene-perception relations as they are involved in judgments of altitude and ground speed as well as of size and distance. Motion as perceived visually is a function of dynamic distance cues, and hence depends on changes in $\underline{h}'$ and $\underline{D}'$, that is, $\underline{dh}'$ and $\underline{dD}'$ (assuming $\underline{h}'$ is entirely a function of $\underline{D}'$ and $\underline{H}$; if not, if size constancy is too strong for example, partial differentials are involved). Altitude judgments may depend more on retinal size because of the absence of other vertically oriented cues. This holds at least for persons with little experience looking down on familiar objects--from the top of a tall building, for example. On the other hand, pilots have had a lot of experience looking down, and evidence from the psychology of perceptual development suggests that size judgments, not retinal sizes, would dominate altitude perceptions after some minimal experience of looking down. In such a case, cues from size and linear perspective as provided by surrounding terrain, out to the horizon, also become determiners of perceived altitude.

It should be apparent why, of the multitude of equations describing various aspects of visual perception, equation (3) is stressed here. It deals with drivers of distance perceptions, and the key variables involved, $\underline{h}'$ and $\underline{D}'$, relate directly to the main perceptual problems reported by pilots who assisted in the evaluation: judgments of size, distance, ground speed, and altitude. Furthermore, recent improvements in simulation of scenes can result in size-distance problems simply because size constancy becomes stronger with richness of scenes. Only with barren scenes does perceived size approach retinal size. Visual system engineers focus on retinal size, which worked fairly well for cartoon-like, relatively barren scenes of not long ago. (Even so, tweaking of object sizes was still necessary on occasion.) Although the foregoing discussion did not begin to encompass the full complexity of vision, it is hoped that some useful guidance was provided insofar as size and distance perception is concerned. We turn now to another set of problems.

ILLUSIONS

Illusions are an especially difficult topic to treat briefly. Both their positive and negative effects on perception are wide-ranging and profound. In popular treatments, including many introductory textbooks in psychology, illusions are presented mostly as perceptual anomalies. There is an air of "how 'bout that!" Illusions are more than anomalies. Through mostly unconscious utilization in perceptual processing, they become important bases for structuring perceptions.

The purpose of the following discussion is to illustrate positive roles of illusions in depth perception, and specifically two kinds of illusions that are left out of visual simulation systems. Motion parallax is an obvious example of an omitted positive illusion. At least it is obvious once one ponders it and tries it out to confirm for oneself that motion parallax exists and, through rapid changes in visual fixation, that it is often a primary, even a driving, cue for perceiving self-motion.

When moving along a highway, an observer focuses on an object in a line oblique or perpendicular to the direction of self-motion. Objects and terrain between the observer and the point of focus appear to move backward. that is in a direction opposite observer motion. Objects and terrain beyond the point of focus appear to move in the same direction as self-motion. Thus there are two parallax gradients, one extending from the point of focus back to the observer, one extending from that point to the horizon. For each gradient, the farther objects and terrain are from the point of focus, the more rapid will appear their backward or forward motion. At the limit of actual distance, for example, objects appear to be traveling at the same speed as the observer. Thus the child's exclamation when riding in an automobile, "The moon's racing with us!"

To appreciate the illusory character of the two motion gradients one need only change the distance of the point of focus. Both gradients acquire a new origin. Some portions of terrain that once went backward now go forward, or vice versa. Relative motion gradients change accordingly. In the real world, attack helicopter pilots often change distance of focus by the second, and even more rapidly in confined areas. But a simulated scene shows only one gradient, the near gradient of relative motion in the objective sense, and it begins not at the point of focus but at the maximum viewing range. Thus from a standpoint of motion parallax, <u>everything</u> appears nearer than the point of focus, wherever it might be, because everything moves backward! Even da Vinci can't help us here. Motion parallax can be experienced in some holographic photographs, but holography is not state of the art in visual simulation at present. Until it becomes so, one can expect motion cue incongruence in any visual system used for flights at low altitude. (At high altitudes motion parallax is less apparent, as mathematical projections can show.) At heights such as flown during NOE flight, motion parallax is almost surely a driving cue, one that figures substantially in the calibration of other cues, including apparent size and linear perspective. In fact, it was noticed during the study that when maneuvering around objects in restricted areas, pilots often moved their heads from side to side. This is a very common means of increasing motion parallax in close quarters, and it can be confusing when it fails to work. An immediate conclusion is that $\underline{h}'$ and/or $\underline{D}'$ in equation (3) may need considerable tweaking at low altitudes so as to override the absence of motion parallax.

Positive roles of illusions in perception go far beyond motion parallax. Profound roles, for example, are provided by stereoscopic illusions. In this case we do not mean stereopsis as manifest in binocular disparity or muscular sensations involved in bringing two eyes to focus on the same object. Muscular cues arising from convergence apply only for severely limited distances. Furthermore, muscular convergence cues occur even during monocular viewing. With one eye closed, a perceiver habitually converges the two eyes on the point of focus of the operative eye. Retinal disparity--divergent views of an object due to the two eyes' different viewing points--is another matter. Even so, effective retinal disparity is apparently limited to a little less than 2 seconds of arc in visual angles, and this sensitivity was found under static laboratory conditions.

More important for the simulation of visual scenes are the stereoscopic illusions that have been left out or else confused in simulated visual scenes.

Binocular vision necessarily gives double images at all points except on a horopter determined by the point of focus. That is, views of objects appearing on a distorted arc converge into single stereoscopic images because the convergence of the two eyes is such that the images of a given object have the same functional location on the retina of both eyes. Stimulated points off the horopter fall on the retina at locations that cannot be resolved into one image. The result is two gradients of double images, with "distance" between the double images increasing as a function of distance from the focal point. Mathematical analysis (and experiments) shows that in the nearer gradient, the one between the perceiver and the point of focus, the double images are crossed. The same mathematical analysis will show that images beyond the point of focus do not cross, they diverge. Though the gradients are processed unconsciously, it was found in the nineteenth century that both influence depth perception.

Mathematical analysis of the horopter region, which by no means is a simple projection of objective reality on retinal surfaces, was completed by Hermann von Helmholtz in the mid-nineteenth century. In referring to Helmholtz's and a subsequent analysis, Woodworth and Schlosberg said, "A knowledge of the horopter is of importance in a thorough mathematical analysis of certain aspects of depth perception. . . but for most of us, fortunately, a nodding acquaintance with this complicated topic is sufficient."[1] No longer is this so. One anticipates a visual system designer, in naive joy, believing that binocular cues are completely accounted for when binocular disparity is simulated via, say, separate optic fibers carrying differing visual stimuli to the two eyes. More may be lost than gained if the disparate images apply only to an object of interest. Disparity is not needed that much for flight. What is needed are the binocular illusions--crossed vs. uncrossed images--we regularly depend on for perceiving depth at distances where binocular disparity vanishes.

This limited treatment of useful illusions, together with earlier discussions, shows that the question regarding what is left out of visual scenes has no simple answer. It is suggested that a viable way around the problem is to design scenes with driving cues strong enough to dominate perception. Then, perhaps, what has been left out will not be missed. Cartoonists do this extremely well. As Dieterly[2] suggested, we should ask them how they do it. Mushrooming of size and texture patterns as defined in Section II is probably the most effective device used by animators to give extreme motion effects. If a pilot saw something coming at him, mushrooming in size as regularly depicted in Saturday morning cartoons of the "Road Runner," the pilot is not going to look around for double images or parallax gradients. This is not to say that pilots should always have something coming at them. Rather, it may help just to manipulate mushrooming, even to exaggerate it under certain circumstances, as any object is approached so as

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[1] Woodworth & Schlosberg, Op. cit., 1954, p. 461.

[2] Dieterly, D. L. Visual illusions and visual simulation. Image II Conference Porceedings, Scottsdale, AZ, June 1981.

to increase the dominance of changes in retinal and apparent sizes. There are techniques for doing this that will work in visual systems, but they cannot be explored here. The mushrooming example was only to illustrate the more general point that designers of visual systems should manipulate cues they can deal with in ways that minimize negative effects of omitting cues they cannot represent.

SIMULATOR SICKNESS

As suggested earlier, the incidence of simulator sickness may be increasing. Evidence of an increase is not clear-cut, for occasional studies of 25 or more years ago reported high percentages of pilots experiencing discomfort in some form, even up to 75% or so. Whether or not the problem is increasing, concern with it certainly is, as evidenced, for example, by a fairly recent workshop on the subject sponsored by the National Research Council. The proceedings of the workshop[1] give a fairly comprehensive summary of what is known or suspected regarding simulator variables that correlate with sickness, so there is no need to review this information here. Rather, the present discussion is restricted to what observations made during the VSCDP evaluation may imply concerning the problem, and what simulator sickness during the evaluation may imply concerning the GE system.

All pilots who assisted in the evaluation experienced discomfort of some kind. In most cases it was either mild or temporary, or both. The problem was so intense with one pilot, however, that debilitating nausea set in almost immediately on two attempts to fly the system. Three other pilots became nauseous enough that careful pacing of flights and durations was necessary. Besides nausea, headaches were experienced by five of the nine pilots, and motion disorientation or vertigo was reported by three pilots. In addition, one of the investigators, a nonpilot, reported fairly intense vertigo immediately following (but not during) flights. Appendix E summarizes this information as it was obtained during interviews. (See item 4 on the debriefing guide in Appendix C.)

Conflicts in Visual Cues or in Adaptation?

Incongruence of cues has long been considered a sufficient, if not necessary, condition for motion sickness. It is natural therefore to suspect cue conflicts when pilots become ill during simulator flights. The validity of the cue-conflict theory has not been established for either motion or simulator sickness. It is the most commonly accepted theory, however, so it would be well to summarize earlier points regarding incongruence of visual cues in the GE system.

The major point brought out earlier was that pilots apparently could find no consistent basis for imposing coherence in size and distance perception when viewing scenes as a whole. Contexts often did not permit selection of

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[1] McCauley, M. E. (Ed.). Research issues in simulator sickness: Proceedings of a workshop. Washington, DC: National Academy Press, 1984.

usable cues to drive the calibration of cue metrics. Indeed, two common drivers, perceived size and linear perspective, were sometimes themselves mutually incompatible except for near scene characteristics. The lack of motion parallax and binocularly crossed images further complicated the problem, because motion parallax at least is often a key driver. In addition, brightness or intensity gradients appeared awry if not missing entirely. The overall effect was certainly cue incongruence. Perhaps a more appropriate term is cue ambiguity, because the latter term connotes specifically a failure to resolve cue conflicts so as to emerge with a unified perceptual structure.

In spite of the prevalence of these ambiguities, it is by no means clear that, in and of themselves, they would produce illness. One can stare at optical illusions for hours with no discomfort other than perhaps a growing awareness that he is being rather stupid about it all. In other words, the cue conflicts summarized above can be expected to affect judgments of size, distance, ground speed, and altitude, just as common optical illusions distort relations among scene components. But producing illness is quite a different matter. If cue conflicts are really the problem, one must go beyond these sorts of visual confusion alone. One must look into nonvisual sources of conflicts as well.

In view of this point, a gross distinction in kinds of simulator sickness is in order. Headaches and nausea, especially intense nausea, can arise from different sources. Thus, grouping all kinds of discomforts under "simulator sickness" can be misleading. Certain scene characteristics can surely lead to eyestrain and thus headaches. For example, in trying to assess a problem he had on occasion with texture patterns in the GE system, one of the investigators later viewed several moiré patterns that were published several years ago in Scientific American.[1] With some patterns, eye discomfort was apparent after only a few seconds' viewing time. The eye could not find a stable focus. Constant adaptation resulted, apparently through muscular adjustments of several times per second. Only a deliberate focus on a scene driver, and then only when one could be located, eased the confusion. (It did not remove the confusion, however.) This confusion with moiré patterns is almost universal among observers, which is why French moiré silk was once so chic. Continued viewing of patterns of this sort can produce eyestrain and concomitant headaches. It may or may not result in nausea. If it does, nausea would probably be a derivative malady, not a primary effect of viewing the patterns.

The occasional difficulty with moiré effects in GE scenes arose from texture patterns. They were controllable, however, and usually transitory. The problem could have been jittering of scenes. This would be especially likely when one was in a rotational movement while the scene jitters, for this would duplicate conditions which create moiré patterns.[2] Jittering may also have

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[1]Oster, G., & Nishijima, Y. Moiré patterns. Scientific American, May 1963, No. 299. This article not only gives excellent examples of moire patterns, the authors explain how they are created.

[2]See Oster & Nishijima, Idem.

had effects on pilot comfort that did not involve moiré patterns. Saccadic eye movements, normal during visual pursuit, become unnatural when the entire scene jumps around; and optic nystagmus is increased even though the observer is stationary and only the scene moves. Just a scene rotating in any plane can induce nystagmus in a stationary observer, resulting in a feeling of dizziness. Some pilots in the study were especially vulnerable to simulated bank rotations, and there have been a number of instances reported where rapid 180° turns when taxiing simulators induced considerable head and eye discomfort.

To summarize to this point, conflicts among visual cues as discussed heretofore do not really explain the incidence of simulator sickness reported by the pilots in this study. Even visual conditions that were likely to cause some forms of discomfort such as dizziness and headaches seem to have involved not so much cue conflicts as perceptual processing variables. Specifically, the perceiver had difficulty adapting visual mechanisms to the visual conditions--finding a focus in moiré patterns, maintaining normal saccadic movements, successive focusing on rotating patterns. Cue conflicts may underlie adaptation problems, but if so one must dig deeper into motion cueing than phenomenal vision alone.

Another adaption problem may underlie a complaint by some pilots in the study regarding the low resolution and illumination level outside the AOI. As mentioned earlier, two relatively independent visual processes are involved when illumination level permits. One process governs focal vision and attention--the part we are most aware of. As explained, this process permits such things as maneuvering around obstacles. The second process, which is largely unconscious, utilizes information from general scene contexts as a functional framework for the focal process. At low levels of illumination, the second process becomes less and less operative, and one learns early in life to adapt to the loss of information by trying to base actions (and perceptions) on focal stimuli. A conflict, not of cue information but what to pay attention to, naturally would arise if the illumination level outside the AOI is high enough to try to use contextual cues, but the resolution is too low outside the AOI for the cues to be clearly discerned. (This is not to mention the stark contrast in brightness between the AOI and background.) Successful adaptation in such a case may call for suppressing all information outside the AOI, or else manipulating the AOI so that contextual information can be acquired sequentially (not concomitantly) with focal information. Sequencing of AOI loci was necessary under night and FLIR conditions, which is a natural kind of experience. It is not natural under day conditions, and if one does not learn to do it, an unresolved need for ambient adaptation remains. It is significant that pilots had little if any discomfort during dawn-dusk and night flights. (However, no pilot began with flights under these conditions. Thus, it is not known whether the reduction in simulator sickness was due to removal of need to adapt to limited, actually poor, contextual information or to an adaptation to the visual conditions in other respects.)

The above point leads directly to another one, which in turn will lead to an important conclusion regarding possible roles of visual systems in simulator sickness. Simulator sickness seems to be more likely with a wide FOV than with a narrow one. Obviously, the wider the FOV, the more ambient (contextual) information available. If this information cannot be processed

readily for whatever reason, especially conflicts with nonvisual motion cues, an adaptation problem arises. When watching television in one's home, regardless of what happens on the screen it is localized within the confines of the screen. The viewer is not involved. The context provided by the viewing room is dominant, and any actions displayed on a TV are seen as relative to stable perceptual coordinates provided by the room context. Objects may rotate on the screen, but the viewer does not rotate.

This point is both obvious and profound. The profundity lies in the fact that perceivers adopt functional external coordinates to interpret what they see. We cannot develop the full implications of externalized referent coordinate systems here; the reader is referred to Osgood[1] for an insightful treatment. We simply make the point that as the TV or movie screen becomes larger, the stable room has less impact on defining the referent coordinates. The success in the 1950's of Cinerama, with its wide screen, in forcing movie audiences to feel motion was due to the dominance of the wide screen display. No longer was the audience watching a scene that was dwarfed by the surrounds of a theater. The movie dominated the visual environment. In doing so, referent coordinates became externalized to the screen, not to a stable theater. No wonder audiences screamed. They became participants in whatever was going on. In a perceptual, even though not in an objective sense, they were literally part of the action.

In the typical simulator cockpit all one can see are cockpit structures, flight instruments, and what is displayed by a visual system. The pilots in this study did not have a cockpit or flight instruments for reference. An FOV wide enough to encompass the functional range of vision became the only visual context for externalizing a referent coordinate system for interpreting motion cues. Hence, self-motion was experienced. In fact, one pilot, who had considerable experience in simulators, said, "I have always insisted that simulators have to have a motion system. I state now that I've changed my mind. You don't need motion [with the GE system]." An objection is raised below to the final conclusion, but the testimony confirms the applicability of the foregoing analysis in understanding the impact of recent visual simulation technology on problems that have arisen because of improvements in the state of the art. It is pointed out once more that FLIR--as with a TV in a room at home--apparently gives no problems. Problems arise when the visual scene is dominant enough to force referent coordinates for the visual environment to be located in the scene itself.

Nonvisual Perception of Motion

Even an outline of nonvisual cues in motion perception is beyond the scope of this report. The purpose of the present discussion is only to indicate briefly what was meant by earlier statements that one must go beyond visual cues alone to explain the more intense manifestations of simulator sickness such as nausea. We begin with the fact that simulator sickness other than some headaches appears to arise from experiences of motion. The fact that objective motion may not even be involved is significant in

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[1]Osgood, C. E. Method and theory in experimental psychology. New York: Oxford University Press, 1953.

distinguishing between motion sickness and simulator sickness. If, as explained, external visual referent coordinates are moving, self-motion is an automatic experience. Hence, incongruence of cues must exist to the extent that force-induced sensations of motion do not occur. In this connection, there is considerable evidence that, in visual simulators, experienced pilots are more vulnerable to simulator sickness than are novice pilots. Also, platform motion systems appear to reduce vulnerability in simulators with visual systems. It seems reasonable to conclude that conflicts among visual vs. nonvisual cues are candidate causes of simulator sickness.

Although cue conflicts are thought to lead to motion sickness too, this condition can occur when there are no conflicts among cues in the usual vague meaning of the term. Car sickness, for example, seems more likely if a person is asleep; and one can get seasick on the deck of a heaving boat where visual and nonvisual cues are mutually confirming, not contradictory. It is for this reason that adaptive processing of information has been stressed by some researchers, and especially as concerns feedback-feedforward conflicts in, say, the otolithic system.[1] There may well be conflicts, but they are in the processing of cues, not in phenomenal cues.

To illustrate at a level that shows the complexity of the problem, differences in self-orientation probably account at least partly for variations in vulnerability to both motion and simulator sickness, and in the incidence of nausea (as opposed to headaches, etc.) among pilots in simulators. In gross terms, people differ in the extent they orient self-position according to the visual field as opposed to gravitational forces. In a typical experiment the subject sits in a chair and views a controlled visual field. Both the chair and the field can be tilted, and the tilts can be varied independently. The subject's task is to manipulate a rod suspended before him until he thinks the rod is vertical with reference to gravity. (The subject is aware that his chair and the visual field can be tilted.) Some subjects position the rod mostly according to the visual field, some mostly according to gravity. A technique of this sort clearly shows that people differ in the extent they are visually oriented vs. gravity oriented. The differences have some correlation with more general personality variables of field dependence vs. field independence. A field dependent person tends to structure perceptions (or beliefs, attitudes, etc.) according to external conditions (e.g., external referent coordinates as discussed above). A field independent person is more inclined to rely on internal systems--gravity-induced otolithic sensations in the perceptual task just described, for example.

Suppose a pilot with substantial gravity orientation flies a simulator with no motion system, but with a dominating, realistic visual system with a wide FOV that forces an experience of motion. This pilot will experience cue or processing conflicts that a pilot with strong visual dependence will not notice. Platform motion could well help the first pilot adapt to the simulator. Without platform motion, the first pilot may well become ill, not through motion but because of its absence.

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[1]See McCauley, 1984, op. cit.

Insofar as this analysis applies, motion sickness and simulator sickness are not the same thing. The first is due to motion, the latter to its absence. The analysis also sheds possible light on why experienced pilots, who are almost invulnerable to motion sickness, are more vulnerable to simulator sickness. If, with experience, pilots learn to depend more on gravitational forces than on visual factors, significant components of habitual motion-processing systems are missing in visual simulators having no force motion. Further, the analysis implies that the greatest vulnerability would be during rapid rotational motion where acceleration is greatest--sharp banks followed immediately by sharp counterbanks. Rapid rotations have a great impact on what goes on in the inner ear. In the words of one pilot, "I had to squint my eyes and cut out the visual field during banks and sharp turns." Squinting, of course, reduces the FOV, and thus the dominance of the visual scene. The effect is less confusion in visual and nonvisual sensations.

This discussion could continue at length, and many other factors could be brought in. The purpose is accomplished, however, if it is apparent that all simulator sickness is not simply a matter of conflicts in phenomenal visual cues. Processing of cues within habitual matrices of motion perception, and factors that govern the processing, have to be considered as well. Hence, there is no reason to blame all manifestations of illness experienced by pilots in this study on the GE visual system. Some headaches were perhaps due to scene characteristics, but certainly not immediate onsets of nausea.

CONCLUSIONS

1. The GE visual system examined in this study represents a significant advance in visual simulation for flight training.

2. After appropriate development and adjustments, the GE system can support essentially all aspects of Army helicopter operations that can be carried out in a simulator. This includes flight under daylight, dawn-dusk, and FLIR conditions.

3. The adjustments referred to in the second conclusion concern reducing perceptual conflicts among distance cues, especially as may be done by manipulating apparent sizes of objects and linear perspective.

4. Texture patterns would be more effective if they included:

   a. three-dimensional irregularities;

   b. gradient qualities that closely followed relative size and linear perspective;

   c. intensity gradients.

5. Intensity gradients should be provided at least as they affect hue saturation; brightness gradients would also be desirable, but due to low overall illumination, true brightness gradients may result in illumination levels that are too low.

6. Visual system designers should make a concerted effort to incorporate the projective geometry of perception into visual scenes, as opposed to only projective geometry of objective reality, taking artistic license as necessary.

7. The asymptotic approach to the geometry of perception discussed in Section III should be tried, especially since this approach should reduce effects of individual differences on scene interpretations.

8. There was a high incidence of simulator sickness experienced by pilots who assisted in the evaluation, but all discomforts cannot be ascribed entirely to the GE visual system per se. Some headaches, and perhaps some vertigo and dizziness, could well be due to scene characteristics, but the more serious problems appear to derive from the processing of motion cues.

9. With respect to the eighth conclusion, the GE visual system is sufficiently dominant to induce intense experiences of motion in pilots, and adaptive processing of motion cues is probably confused because of the absence of nonvisual motion cues.

10. GE and other manufacturers of visual systems should diligently pursue research to clarify problems in simulator sickness and to reduce its incidence. A simulator cannot be used for training if it makes pilots sick.

Several of the conclusions suggest a need for research and development. Specific suggestions of what can be done were made at various points in the report. However, it was beyond the scope of the study to explain how the suggestions might be implemented in the engineering of visual systems. Also, a number of other factors could have been mentioned. Those that were discussed were selected because of their immediate relevance to problems discussed during the evaluation.

APPENDIX A

PILOT BRIEFING GUIDE

1. Purpose of test: to determine to what degree this visual scene provides the helicopter pilot the visual cues required for flight, and especially nap-of-earth (NOE) flight tasks. Emphasize that the purpose is to evaluate the visual system, not the pilot's performance. The pilot is assumed to be an expert helicopter pilot.

2. Visual gaming area limitation: The specific visual scene at present is a 1 X 5 nm block of Hunter-Liggett with a band of another 1 nm around the block. The movements of threat vehicles are limited to the 1 X 5 nm block. The pilots will necessarily be constrained to this small gaming area for the test. To the extent feasible, realistic attack helicopter doctrine and procedures will apply while performing the NOE tasks. The pilot should remember that this particular device set-up is not being checked or accepted for Army training; we are only evaluating the visual scene content. The technology behind the scenes may be adapted and used in future training devices.

3. Flight controls and indicators: These controls and their responses represent no actual helicopter. They are simply a cost-effective means of providing rudimentary flight and power-control input. Each pilot will require some practice to "get the feel" and to perform the various flight tasks reasonably. He should not be concerned about these controls and their response deficiencies. They are rudimentary, so the pilot should just do as well as he can.

4. Missions to be flown: The attack ATM provided the set of tactical tasks to be flown. Initially, each pilot will spend a period just learning to fly the system while performing basic flight tasks. On the subsequent flights, the tactical flight form will be fairly comprehensive. The

study team will observe and complete the data recording, using a combination of subjective and objective observations to rate each task's visual support. (As explained in the text, it was necessary to have the pilots, instead of the study team, complete rating scales.)

5. Training sessions management: Initially each pilot will complete a biographical questionnaire that provides information necessary for use later when the data are analyzed and during preparation of the report. Each training block will initially be scheduled for four hours; this should decrease as we progress. The first hour will be used to cover the briefing, then the flight (1-2 hours when feasible) will commence. Where possible, we prefer that pilots fly mini-Army scout/attack missions, realizing that the very small visual gaming world will require some imagination. The pilots should use standard procedures. A break may be desirable depending on the flight difficulty and other unknown factors. The pilot will try to fly as many of the tasks as time permits. The debriefing should require about one hour initially. It's purpose is to ask the pilot specific questions emphasizing the visual scene to identify how well tasks can be performed and any problems that occurred. The pilots are encouraged to make any comments concerning their observations and opinions. It is hoped that each pilot will fly one FAM and about three or four tactical flights during the test. It is desired that no pilot fly more than one flight per day the first week. (Schedules of availability of pilots and the equipment made multiple flights on a given day necessary in several instances.)

APPENDIX B

ANCHORS FOR RATING

VISUAL SUPPORT

Bear in mind that application of the criteria below should be independent of the problems pilots have with the rudimentary control system. The question is, How adequate would the system be <u>if</u> realistic controls had been available?

1. <u>Clearly inadequate</u>: Pilot does not have sufficient visual information to control flight, anticipate maneuver requirements with respect to objects and terrain, and/or assess the status of a maneuver.

2. <u>Questionably adequate</u>: Under- and/or overcontrol occurs frequently; must make last-second adjustments because visual scene not adequate at beginning of maneuver for smooth coordination of an entire maneuver; considerable practice required, after control mastery, to adapt to system.

3. <u>Generally adequate</u>: Under- and/or overcontrol occurs rarely if at all; maneuvers can be pursued with smooth coordination throughout as they progress; principal difficulties relate not to scene content, but to mechanics of system operation (e.g., transport lag, system sync, helmet or eye tracker, etc.); minimal practice needed to adjust to system once controls are mastered.

4. <u>Completely adequate</u>: No scene-related difficulties, nor any due to mechanics of the visual system; maneuvers can be performed immediately once control system is mastered.

APPENDIX C

PILOT DEBRIEFING GUIDE

1. General reactions

   a. Best features

   b. Worst features

2. Difficulties in becoming familiar with system

   a. Flight control

   b. Visual scene

3. Visual cues (specific comments)

   a. Hovering control

      (1) Amount/rate of movement

      (2) Hovering turns

      (3) Usual visual referents you use

      (4) Referents used here

   b. Judge distance above ground and touchdown

   c. Judge distance from and above obstacles

   d. Judge up-down movements

   e. Judge vertical rate of closure

   f. Judge horizontal rate of closure

   g. Identify desirable ground track, then control it

   h. Comments on scene content

      (1) Terrain/object shapes, features

      (2) Terrain/object details

      (3) Terrain/object heights

      (4) Shadows

i. Texture

(1) Terrain

(2) Vegetation and other objects

j. Adequacy of lateral/peripheral scene

k. Pilotage and DR support

(1) Identify features

(2) Judge range

(3) Judge bearing

(4) Judge helicopter and obstacle height

(5) Judge helicopter ground speed

l. Comment on traveling

(1) Low level

(2) Contour

(3) NOE

a. Ability to select and fly appropriate headings

b. Judge altitude over ground and obstacles

c. Judge distance from obstacles

d. Judge ground speed

e. Turn control

f. Masking/unmasking

g. Select various attack positions

h. Acquire visually, identify threats

i. Identify FARP and holding areas

4. Physical discomforts

    a. Headache

    b. Nausea

    c. Other

5. Is a platform motion system needed? A "g" seat?

6. Difficulties with a helmet-driven AOI

7. Other

APPENDIX D

PILOT COMMENTS DURING

INTERVIEWS

1-a. GENERAL REACTIONS: BEST FEATURES

Pilot No. 1: Texturing greatly enhanced hover, especially yaw control.

Pilot No. 2: Overall realistic 3-D scenes, including trees, bushes, threats, and natural contours.

Pilot No. 3: Trees and hills; dust after vehicles; haze with limited visibility.

Pilot No. 4: Trees and provisions for low-level, contour, and NOE flight.

Pilot No. 5: Overall realistic scenes; trees, bushes, obstacles easy to identify; range and altitude estimates can be made after practice.

Pilot No. 6: Terrain where small bushes are intermixed with trees; detail of trees in AOI when 100-200 meters away.

Pilot No. 7: Cues at medium and far distances; contours.

Pilot No. 8: Close-in perceptual support; scene realism.

Pilot No. 9: Trees, bushes, rolling hills, and dust from vehicles.

1-b. GENERAL REACTIONS: WORST FEATURES

Pilot No. 1: Shape and sizes of trees degraded ability to judge altitude and distance; relative movement of ground texture confused speed estimate.

Pilot No. 2: Head-stomach discomfort during positive roll, and lateral and to some extent yaw movements.

Pilot No. 3: Unrealistic roads and river beds; flat (i.e., smooth) terrain surfaces; sudden emergence of dust trails; gaming area too small.

Pilot No. 4: Lack of close-in resolution; river beds too rectilinear.

Pilot No. 5: Sharp edges of terrain; improper (sic) and unrealistic grouping of trees; lack of variation in tree sizes; poor representation of rotor disc; scenes too sterile--need clutter; cannot touch down on any but flat areas.

Pilot No. 6: Flat terrain (surfaces)--no relief except textural differences; no small bushes, rocks, etc., to provide uneven ground.

Pilot No. 7: Relative sizes; lack of close-in resolution; difficulties in estimating altitude, range, and speed.

Pilot No. 8: Poor cues (resolution, density) outside AOI; head tracker not adequate for natural eye movements in scanning periphery for reference.

Pilot No. 9: Range and ground speed estimates; too many straight lines (roads, rivers, etc.); all trees appear same height when 2-3 km away, regardless of actual height.

2-a. FAMILIARIZATION DIFFICULTIES: CONTROLS

Pilot No. 1: Not representative of conventional controls; "collective" worked backward.

Pilot No. 2: No big problem, but occasionally moved collective wrong way.

Pilot No. 3: Not representative of conventional controls-- unnatural.

Pilot No. 4: None.

Pilot No. 5: Totally unrealistic; no instrumentation.

Pilot No. 6: Easy to fly, but does not have feel of an aircraft.

Pilot No. 7: None.

Pilot No. 8: Occasional unnatural response to inputs, resulting in uncoordinated control-response relations.

Pilot No. 9: (Helicopter) controls difficult at best; joy stick much better.

2-b. FAMILIARIZATION DIFFICULTIES: VISUAL SCENE

Pilot No. 1: Adjusting to AOI transitions (too stark); peripheral scenes not focused.

Pilot No. 2: AOI contrast; fuzziness of close scenes.

Pilot No. 3: None, but too man-made.

Pilot No. 4: Jitter in AOI very distracting.

Pilot No. 5: Initial judgments of near distances and altitude.

Pilot No. 6: Range estimations; object sizes appeared distorted.

Pilot No. 7: Estimating distance, size, and altitude; discomfort from lateral movements and roll axis changes.

Pilot No. 8: None, but detail close to aircraft needed.

Pilot No. 9: Initial judgments of speed--need more terrain density; some initial navigation difficulties.

3-a-1. ADEQUACY OF VISUAL CUES: AMOUNT/RATE OF MOVEMENT DURING HOVER

Pilot No. 1: Adequate for task standards per ATM manuals.

Pilot No. 2: Had to depend on far rather than near cues due to fuzziness of the latter; hence, some difficulty in lateral, fore-aft and vertical speed control.

Pilot No. 3: Hard to judge rates.

Pilot No. 4: Adequate; no problems.

Pilot No. 5: Some initial difficulty, but temporary; resolution needed outside AOI.

Pilot No. 6: Seemed about right.

Pilot No. 7: Forward and lateral displacement difficult to judge; close-in focus needed.

Pilot No. 8: Adequate; no problems.

Pilot No. 9: No problems; easy to judge (on later flights, noticed difficulty in rate of movement above 15-20 ft altitude).

3-a-2. ADEQUACY OF VISUAL CUES: HOVERING TURNS

Pilot No. 1: Easily accomplished.

Pilot No. 2: No problems.

Pilot No. 3: Not enough side view (no problems on later flights).

Pilot No. 4: Altitude control difficult due to lack of focus close in.

Pilot No. 5: Realistic rotor disc needed to maintain clearance.

Pilot No. 6: Satisfactory, but rotor disc inadequacies caused concern when near trees.

Pilot No. 7: Good mid and far cues; rates easy to control and gage.

Pilot No. 8: No problems.

Pilot No. 9: No problems.

3-a-3,4. USUAL VS. VSCDP REFERENTS FOR HOVER

Pilot No. 1: Only one-half as much compensation required as compared to AH-1 and OH-60 simulators; FOV is main issue.

Pilot No. 2: Usually depend on close-in texture, including periphery; had to use far-scene contents with VSCDP because of poor resolution of near scenes.

Pilot No. 3: Usually depend on texture, trees, hills, with good lateral information; used forward trees and hills with VSCDP; would have liked more lateral information.

Pilot No. 4: Depended mostly on trees with VSCDP; usually use grass and low texture.

Pilot No. 5: Usually depend on objects of known size of objects within 50-75 ft, and sometimes horizon. Used trees and near surface texture with VSCDP, although near texture needs improving.

Pilot No. 6: Found most referents needed are in VSCDP, although close-in areas lacking in cue value.

Pilot No. 7: Usually use near ground and its relative movement; depended on mid and far cues with VSCDP, with attention to altitude changes.

Pilot No. 8: Usually assess a scene for cue value and select referents accordingly; used bases of trees in VSCDP for takeoff and landing.

Pilot No. 9: Use trees when available, so no problem with VSCDP; would prefer more near vegetation.

3-b. ALTITUDE (IN HOVER) AND TOUCHDOWN JUDGMENTS

Pilot No. 1: Easy to hover at altitude.

Pilot No. 2: Cannot judge altitude precisely; had to depend on far cues, but could touch down with them.

Pilot No. 3: OK near ground, but problems above 10-20 ft; clear lateral horizon would help.

Pilot No. 4: Difficult because of lack of resolution on near ground.

Pilot No. 5: Difficult without objects in scene; surface texture not adequate (i.e., resolution problems).

Pilot No. 6: Difficult, but because relations of aircraft structures to wide FOV not evident.

Pilot No. 7: Difficult to judge due to lack of close-in (textural) cues.

Pilot No. 8: No problems.

Pilot No. 9: Good visual support, but some problem maintaining altitude above 20 ft.

3-c. JUDGE DISTANCE FROM/ABOVE OBSTACLES IN HOVER

Pilot No. 1: Could be determined within 10 ft except when near a rise where texture became blurred.

Pilot No. 2: Blurred near scenes posed difficulties.

Pilot No. 3: Difficult to make quantitative judgments, but no problems in flight tasks.

Pilot No. 4: No problems.

Pilot No. 5: Not difficult unless object is far away and/or outside AOI.

Pilot No. 6: Distance of far objects difficult to estimate; trees too large.

Pilot No. 7: Distance from objects difficult to estimate; distance above no problem for task performance (e.g., clearance) but quantitative estimates difficult.

Pilot No. 8: Difficulties arise from apparent sizes of trees (too large).

Pilot No. 9: Easy to judge above, but from difficult; improved in all respects with later flights.

3-d. JUDGE VERTICAL MOVEMENTS DURING HOVER

Pilot No. 1: Apparent vertical movements were positive and immediate.

Pilot No. 2: Lack of clear resolution on near texture gave a problem.

Pilot No. 3: No real problems.

Pilot No. 4: No problems.

Pilot No. 5: Easy, even over flat terrain with no obstacles.

Pilot No. 6: Relatively easy.

Pilot No. 7: Fairly easy; contrast easy to distinguish.

Pilot No. 8: No problems.

Pilot No. 9: Good, no problems.

3-e. JUDGE VERTICAL RATE OF CLOSURE

Pilot No. 1: Adequate for NOE.

Pilot No. 2: OK until close, where resolution "melts into a visual glob."

Pilot No. 3: OK near ground, but difficult at altitude.

Pilot No. 4: No problem.

Pilot No. 5: Fairly easy even over flat terrain with no obstacles.

Pilot No. 6: Last 100 ft difficult because of unknown size of aircraft and height of trees.

Pilot No. 7: Difficult because cannot judge altitude.

Pilot No. 8: No problems.

Pilot No. 9: Good support, but some problem keeping vertical speed slow enough.

3-f. JUDGE HORIZONTAL RATE OF CLOSURE

Pilot No. 1: Adequate for NOE.

Pilot No. 2: OK until close where resolution fails.

Pilot No. 3: OK; easier at low levels.

Pilot No. 4: No problems.

Pilot No. 5: Pretty good, though some difficulty outside AOI.

Pilot No. 6: Relatively easy.

Pilot No. 7: Difficult because cannot judge ground speed.

Pilot No. 8: True size and apparent ground speed do not relate (i.e., tree size does not change at a rate comparable to ground speed).

Pilot No. 9: Ground speed difficult (but no problem on later flight).

3-g. IDENTIFY/CONTROL DESIRABLE GROUND TRACK

Pilot No. 1: Adequate for NOE.

Pilot No. 2: No problem, but was sometimes difficult to see how a valley was turning.

Pilot No. 3: Visual scene OK; problems were with controls for aircraft ("easy" on later flight).

Pilot No. 4: No problems.

Pilot No. 5: No difficulties.

Pilot No. 6: Easy.

Pilot No. 7: Relatively easy.

Pilot No. 8: No problems.

Pilot No. 9: Good support.

3-h-1. COMMENTS RE TERRAIN/OBJECT SHAPES/FEATURES

Pilot No. 1: Shaping and features appear to be adequate to provide desired cues.

Pilot No. 2: Contours and shapes looked too man-made (too many straight edges.

Pilot No. 3: Looks too man-made; trees are all the same type; roads and river beds too straight.

Pilot No. 4: River beds need more shaping, and hills are too smooth; rocks do not look real.

Pilot No. 5: Trees and bushes very good; terrain too sharply featured and surface texture not realistic, especially when blurred on approach; targets nearly impossible to identify (could not identify a T-80 as a tank until within 200 meters).

Pilot No. 6: Trees too uniform, especially outside AOI; changes with AOI too dramatic.

Pilot No. 7: Good except when very close (blurring); edges of washes, river beds too sharp.

Pilot No. 8: Roads not realistic.

Pilot No. 9: Too many straight lines; too many flat surfaces (later flight: hills and trees are good).

3-h-2. COMMENTS RE TERRAIN/OBJECT DETAILS

<u>Pilot No. 1</u>: Tree detail adequate; roads, river beds need work; hill masses could use more detail.

<u>Pilot No. 2</u>: Trees, shrubs good at a distance; blurred up close.

<u>Pilot No. 3</u>: Too unnatural (on later flight, what is there is good but more is needed).

<u>Pilot No. 4</u>: No problems.

<u>Pilot No. 5</u>: Trees and bushes have good detail, but rocks do not look like rocks.

<u>Pilot No. 6</u>: Texture too flat, uniform.

<u>Pilot No. 7</u>: Good at mid to far distances; poor close up.

<u>Pilot No. 8</u>: No problems.

<u>Pilot No. 9</u>: Good, but some rocks are too square.

3-h-3. COMMENTS RE TERRAIN/OBJECT HEIGHTS

Pilot No. 1: Tree sizes/shapes tended to degrade range estimates.

Pilot No. 2: Trees appeared too large, leading to underestimates of range.

Pilot No. 3: Trees appeared too large; hard to judge actual heights no problem in clearing them, however).

Pilot No. 4: Very good.

Pilot No. 5: More variety needed in heights.

Pilot No. 6: Tree size-distance relation did not appear correct.

Pilot No. 7: Trees too tall.

Pilot No. 8: No problems.

Pilot No. 9: Good, but could not judge actual heights.

3-h-4. COMMENTS RE SHADOWS[1]

Pilot No. 1: Did not notice shadows.

Pilot No. 2: Only had straight-down shadows.

Pilot No. 3: OK, but did not really notice.

Pilot No. 4: Saw none.

Pilot No. 5: Shadows from overhead sun not of much use.

Pilot No. 6: Scene not bright enough to notice shadows.

Pilot No. 7: Not a factor.

Pilot No. 8: No problems.

Pilot No. 9: Good.

[1]Daylight scenes were at noon.

3-i-1. COMMENTS RE TERRAIN TEXTURE

Pilot No. 1: Adequate for NOE.

Pilot No. 2: Too generic (i.e., homogeneous; no local variations).

Pilot No. 3: Too flat--yet many hills (i.e., texture is 2-D; 3-D unevenness needed).

Pilot No. 4: Too smooth--very unnatural.

Pilot No. 5: More variation would aid estimates of height and speed, as well as distance.

Pilot No. 6: Too flat (2-D), not enough relief (3-D).

Pilot No. 7: Blurs when close.

Pilot No. 8: More detail needed to judge height, speed.

Pilot No. 9: Variation, break-up needed.

3-i-2. COMMENTS RE VEGETATION/OBJECT TEXTURE

Pilot No. 1: Trees adequate.

Pilot No. 2: Not as concerned with texture as with lack of realism.

Pilot No. 3: Not as concerned with texture as with lack of small vegetation.

Pilot No. 4: Trees were excellent.

Pilot No. 5: Trees, bushes pretty good; roads did not look like roads.

Pilot No. 6: Small bushes looked good.

Pilot No. 7: Disappears when close up; too homogeneous overall.

Pilot No. 8: Helps to control speed and altitude.

Pilot No. 9: Good--need some small bushes, rocks, dead trees.

3-j. ADEQUACY OF LATERAL/PERIPHERAL SCENE

Pilot No. 1: Adequate for NOE.

Pilot No. 2: A big problem due to blur when outside AOI; could result in false speed cues.

Pilot No. 3: Had no problems, but would like to see more without shifting AOI.

Pilot No. 4: Problem with discrete break in clarity at edge of AOI.

Pilot No. 5: Not clear enough outside AOI.

Pilot No. 6: Peripheral scene not distinct enough, but lateral scene about right.

Pilot No. 7: Adequate.

Pilot No. 8: Trees tend to pop up when flying at higher speeds.

Pilot No. 9: Good--a little faded and fuzzy, but usable.

3-k-1. ADEQUACY OF SCENE FEATURE IDENTIFICATION FOR PILOTAGE/DR NAVIGATION

Pilot No. 1: Adequate for NOE.

Pilot No. 2: Got lost often (only a real-world map available, and it was too small a scale).

Pilot No. 3: Roads are poor; OK on a later flight.

Pilot No. 4: No problems.

Pilot No. 5: No problems within AOI.

Pilot No. 6: Relatively easy to identify.

Pilot No. 7: Good.

Pilot No. 8: No problems.

Pilot No. 9: Good.

3-k-2. ADEQUACY OF SCENE FOR RANGE ESTIMATIONS

Pilot No. 1: Too-large trees degraded range estimates.

Pilot No. 2: Big problem--tree and vehicle sizes out of line.

Pilot No. 3: Poor--trees too large.

Pilot No. 4: No problems (but limited opportunities).

Pilot No. 5: Some problem because of trees and their lack of variety.

Pilot No. 6: Referents required were not there--very difficult.

Pilot No. 7: Trees too large.

Pilot No. 8: Tanks look farther away than trees (of same location)--hence, estimates depend on what is being considered.

Pilot No. 9: Difficult; an accurate map with grid squares would solve the problem; trees too large.

3-k-3. ADEQUACY OF SCENE FOR BEARING JUDGMENTS

Pilot No. 1: Adequate for NOE.

Pilot No. 2: Not relevant with no compass available.

Pilot No. 3: Same as Pilot No. 2, but considered "pretty good" on a later flight.

Pilot No. 4: Some difficulty, but it could be learned.

Pilot No. 5: Judging bearing of objects from aircraft is acceptable, but absolute bearing difficult (no compass).

Pilot No. 6: Relatively easy.

Pilot No. 7: Difficult to do.

Pilot No. 8: Should be no real problem, given compass; OK on later flight.

Pilot No. 9: Good map would solve any problems; OK on later flight.

[1] No compass was available, and ambient cockpit light did not permit use of a map.

3-k-4. ADEQUACY OF SCENE FOR JUDGING HELICOPTER/OBSTACLE HEIGHT

Pilot No. 1: Adequate for hover; slightly degraded during forward flight.

Pilot No. 2: Very difficult; one can fly into surface, believing he is at 5-10 ft altitude.

Pilot No. 3: Good, especially near ground.

Pilot No. 4: Some problems but can be overcome with experience with the system.

Pilot No. 5: Experience with system will remove problems re helicopter height; object height difficult because there is no known standard for comparison.

Pilot No. 6: No problems.

Pilot No. 7: Hard to size obstacles.

Pilot No. 8: No problems.

Pilot No. 9: Aircraft height no problem (later flight: except above 20 ft); difficult to judge obstacle height; no problem in learning to do so, however.

3-k-5. ADEQUACY OF SCENE FOR JUDGING SPEED

Pilot No. 1: Felt was flying slower than actually was when at low altitude.

Pilot No. 2: Close-to-ground speed looked too fast; above 30-50 ft looked very slow.

Pilot No. 3: Difficult because trees confuse distances.

Pilot No. 4: No problems.

Pilot No. 5: Pretty easy to judge close to ground, but gets somewhat difficult at higher altitudes.

Pilot No. 6: Speed seems high close to ground; more realistic at higher altitudes.

Pilot No. 7: Difficult because in-close cues not sufficiently detailed.

Pilot No. 8: Changes in tree sizes do not relate to apparent ground speed; more ground detail would help.

Pilot No. 9: Could not do accurately.

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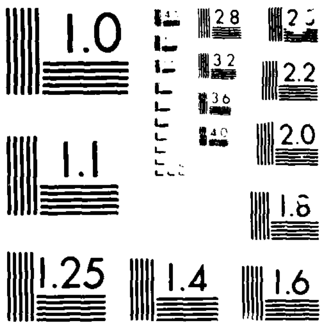

MICROCOP CHART

3-1-1. COMMENTS RE LOW-LEVEL FLIGHT

Pilot No. 1: Adequate cues provided.

Pilot No. 2: No real problem.

Pilot No. 3: Problems at first, OK on later flight.

Pilot No. 4: No problems.

Pilot No. 5: No problems.

Pilot No. 6: Easy to do.

Pilot No. 7: Not difficult, but could not tell how much vertical clearance there was.

Pilot No. 8: No problems.

Pilot No. 9: Easy to do, no problems.

3-1-2. COMMENTS RE CONTOUR FLIGHT

Pilot No. 1: Adequate cues provided.

Pilot No. 2: Some difficulty judging altitude above contours due to their smoothness.

Pilot No. 3: OK, no problems.

Pilot No. 4: No problems.

Pilot No. 5: Some difficulty judging distance/speed, especially crossing ridgelines, due to sharpness of terrain and poor texture (see comments on 3-i).

Pilot No. 6: Relatively easy.

Pilot No. 7: Not too difficult, although could not tell how much vertical clearance was maintained (no danger of contact with obstacles/terrain, however).

Pilot No. 8: No problems.

Pilot No. 9: Good, no problems.

3-1-3-a. COMMENTS RE NOE HEADINGS/TRACK

Pilot No. 1: Adequate cues provided.

Pilot No. 2: Able to do after practice, though valley headings difficult to identify when approaching intersections.

Pilot No. 3: OK once a heading/track selected; map needed.

Pilot No. 4: (Did not fly NOE due to illness).

Pilot No. 5: No problem with track; headings are not particularly important in NOE.

Pilot No. 6: No problems.

Pilot No. 7: Track (apparently) no problem; headings per se not applicable with no compass.

Pilot No. 8: No problems.

Pilot No. 9: No problems (when oriented with map).

3-1-3-b. COMMENTS RE NOE ALTITUDE JUDGMENTS

Pilot No. 1: Cues adequate for hover, slightly degraded during forward flight; felt was flying slower (apparently) because of confusion regarding altitude.

Pilot No. 2: Had to use far cues since close-in cues were blurred; felt comfortable that obstacles would be cleared, but could not say by how much.

Pilot No. 3: General dissatisfaction because of lack of realism, but had no trouble clearing obstacles.

Pilot No. 4: (Did not fly NOE due to illness.)

Pilot No. 5: Difficult over flat terrain due to poor surface texture--does not change with altitude.

Pilot No. 6: Somewhat difficult because of unknown tree height and relative size of aircraft.

Pilot No. 7: Difficult to size obstacles.

Pilot No. 8: Low altitude no problem.

Pilot No. 9: Can be difficult above 20 ft, but becomes easier with practice.

3-1-3-c. COMMENTS RE NOE OBSTACLE DISTANCE JUDGMENTS

Pilot No. 1: Both in hover and forward flight distances could be determined within 10 ft; ridge texture softened (blurred) upon approach, which gave trouble in distance judgments.

Pilot No. 2: Had to use far cues; knew obstacles would be cleared but could not say how much; good rotor disc simulation would help.

Pilot No. 3: Poor at first, but OK on later flight; had no problems with flight at any time, however.

Pilot No. 4: (Did not fly NOE due to illness.)

Pilot No. 5: Generally not too difficult, but a better representation of rotor disc is imperative.

Pilot No. 6: Most difficulty due to lack of detail when close; could avoid obstacles, however.

Pilot No. 7: Tree sizes a problem; did not hit any but did not know how much they were cleared.

Pilot No. 8: No problems.

Pilot No. 9: Difficult in areas of low (or no) vegetation; tree sizes a problem; could clear easily, however.

3-1-3-d. COMMENTS RE NOE SPEED JUDGMENTS

Pilot No. 1: When low, felt was flying slower than actual--was confused by altitude judgments.

Pilot No. 2: Uncertain, but felt could judge within 25 knots.

Pilot No. 3: Cue support was poor (had difficulty).

Pilot No. 4: (Did not fly NOE due to illness.)

Pilot No. 5: Generally no problem at true NOE altitudes.

Pilot No. 6: Difficult when close to ground.

Pilot No. 7: Difficult because close-in cues blur, disrupting sense of speed.

Pilot No. 8: No problems.

Pilot No. 9: Difficult, but may be due to nature of cockpit controls.

3-1-3-e. COMMENTS RE NOE TURN CONTROL

Pilot No. 1: Adequate for NOE flight.

Pilot No. 2: No problem (used far cues for this purpose).

Pilot No. 3: OK, though controls were unnatural.

Pilot No. 4: (Did not fly NOE due to illness.)

Pilot No. 5: No problem at less than 50-60 knots; disorientation induced at higher speeds because of lack of (force) motion cues.

Pilot No. 6: Relatively easy.

Pilot No. 7: OK, no problems.

Pilot No. 8: No problems.

Pilot No. 9: Good, no problems.

3-1-3-f. COMMENTS RE NOE MASKING/UNMASKING

<u>Pilot No. 1</u>: Adequate for NOE flight.

<u>Pilot No. 2</u>: Could identify positions and could maneuver laterally and vertically until close in (blurring when close).

<u>Pilot No. 3</u>: Side view look-down/peripheral orientation lacking, giving difficulties.

<u>Pilot No. 4</u>: (Did not fly NOE due to illness.)

<u>Pilot No. 5</u>: OK but better surface texture and rotor disc display are needed.

<u>Pilot No. 6</u>: Easy to do.

<u>Pilot No. 7</u>: (Did not attempt.)

<u>Pilot No. 8</u>: No problems.

<u>Pilot No. 9</u>: OK, no problems.

3-1-3-g. COMMENTS RE NOE SELECTION OF ATTACK POSITIONS

Pilot No. 1: Adequate for NOE flight.

Pilot No. 2: Could identify at a distance and maneuver laterally and vertically, but some difficulty when entering (blurring of near scenes).

Pilot No. 3: OK, but better map and longer planning time needed.

Pilot No. 4: (Did not fly NOE due to illness.)

Pilot No. 5: No problem after practice.

Pilot No. 6: Easy to do.

Pilot No. 7: (Did not attempt.)

Pilot No. 8: No problems.

Pilot No. 9: No problems.

3-1-3-h. COMMENTS RE THREAT ACQUISITION/IDENTIFICATION

Pilot No. 1: Threats too small to identify at 1000 meters, even as to type of vehicle; no problem in real world.

Pilot No. 2: Could not see beyond 1500-2000 meters; 500-1000 meter distance necessary to identify type of vehicle; these distances are much closer than necessary in real world.

Pilot No. 3: Good, but not realistic.

Pilot No. 4: (Did not perform due to illness.)

Pilot No. 5: Acquisition is adequate, but identification difficult to impossible even at 1500 meters.

Pilot No. 6: Easy to determine vehicles are present, but difficult to identify type of vehicle.

Pilot No. 7: (Did not attempt.)

Pilot No. 8: Targets too small for range; were not visible when visibility conditions would have allowed them to be.

Pilot No. 9: OK, no problems.

3-1-3-i. COMMENTS RE IDENTIFICATION OF FARP/HOLDING AREAS

Pilot No. 1: (Did not attempt.)

Pilot No. 2: Could pick suitable areas.

Pilot No. 3: Depends on prior map work.

Pilot No. 4: (Did not attempt due to illness.)

Pilot No. 5: No major problems.

Pilot No. 6: Relatively easy.

Pilot No. 7: (Did not attempt.)

Pilot No. 8: No problems.

Pilot No. 9: OK, no problems.

5. IS A PLATFORM MOTION SYSTEM OR G SEAT NEEDED WITH THE VISUAL SYSTEM?

Pilot No. 1: Yes for at least one or the other, preference for platform motion.

Pilot No. 2: Would guess yes for some kind of motion cueing, because it may reduce simulator sickness (a research issue).

Pilot No. 3: No.

Pilot No. 4: Yes to one or the other--pilots want to feel what the eyes see.

Pilot No. 5: Yes--very much so--to control nausea.

Pilot No. 6: No g seat, but platform motion for banked turns.

Pilot No. 7: Yes to one or the other for correlation with visually perceived motion.

Pilot No. 8: No belief one way or the other.

Pilot No. 9: No.

6. DIFFICULTIES WITH HELMET-DRIVEN AOI

Pilot No. 1: AOI transition to periphery was too stark and tended to distract attention (i.e., blurring of non-AOI areas stood out because of difference).

Pilot No. 2: AOI jittered at times, possibly increasing nausea problem.

Pilot No. 3: AOI needs to be larger.

Pilot No. 4: No problems.

Pilot No. 5: No problems, possibly due to experience with IHADSS.

Pilot No. 6: No problems.

Pilot No. 7: Could be larger; items tended to "melt" in and out of AOI (system-caused jerks were bad for a while with this pilot).

Pilot No. 8: Does not slew fully to extremes of scene; eye movements need tracking, not head alone (but no serious problems).

Pilot No. 9: No problems.

APPENDIX E

ILLNESSES AND DISCOMFORTS

EXPERIENCED BY PILOTS

For reasons explained in the text, simulator sickness is becoming a concern in pilot training. Comments by pilots concerning physical discomforts during VSCDP flights are thus provided in a separate appendix to facilitate reference. The comments below were obtained in connection with question no. 4 of the interview guide.

Pilot No. 1: No headache, but during aggressive maneuvering became moderately nauseous with helmet off (i.e., stationary AOI); only slightly nauseous with helmet on during aggressive maneuvering. Had experienced nausea only once before--during R&D testing for UH-60 simulator--and when motion system was not operating. Similar or longer flights in the UH-60 simulator with motion resulted in no nausea.

Pilot No. 2: Any rapid rate of change in roll or yaw (but not pitch) instantly resulted in head discomfort, and slight to moderate nausea very soon after; learned to cope by squinting eyes to cloud the FOV (in bad cases, closed eyes entirely for a few seconds).

Pilot No. 3: Headache after 45 minutes on first flight; no headache or nausea on later flight under dusk conditions. There was some motion disorientation--a feeling of "losing it"--during abrupt turns, especially when a rapid left turn was followed immediately by a rapid right turn, or vice versa. (There seems to have been some concern that he felt motion even though seat was stationary.) Had no problems in past simulator experiences.

Pilot No. 4: No headache, but severe nausea of rapid onset, especially after (normal) horizontal head movements and any degree of turn or bank. Became very hot in cockpit. Had experienced no physical problems in simulators previously.

Pilot No. 5: No headache, but disorientation and probably nausea could be induced from lack of force motion cues coupled with scene movements.

Pilot No. 6: No headache, but hard left banks gave slight nauseous discomfort. "The system will involve you enough to work up a sweat."

Pilot No. 7: Headache, hot flashes, and nausea attributed to visual movements in absence of physical sensations. Worst in roll axis and lateral movements. (Required 30-60 minutes to recover after first flight, but only 5 minutes after second flight.) Less noticeable with dusk, FLIR, reduced visibility.

Pilot No. 8: Headache, nausea, and vertigo when aircraft did not respond as expected or when terrain jumped for no reason (i.e., scene jitters not due to aircraft motion); heat build-up in helmet fostered nausea.

Pilot No. 9: Headache after first 15 minutes of helmet use; no discomforts at all on later flights.

Comments by one of the investigators, a nonpilot, are appended for the record:

There was no physical discomfort during flights other than excessive sweating in the helmet during the first flight. However, there was brief vertigo and disorientation immediately following each flight, and it was intense enough that no attempt was made to leave the seat for a minute or two. Even then, care was taken not to look at the scene, which by this time was usually immobile. Upon leaving the laboratory for the day, there was an occasional awareness while riding in (not driving) a car that one could not suddenly rise up and pass over a car in front. Just the sudden occasional awareness of the difference between the simulator experience and the real world indicates some continuing effect of the simulator experience, and this

point is mentioned because concern has been expressed in the past about effects of simulator experiences that may endure for several hours. There is also a fear that such effects can endanger the participant, especially while driving a car.

END

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